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A Review of Phase Correction Methods for Partial Fourier Reconstruction of MRI

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Abstract— **Partial sampling of K-space data is the conventional method of image reconstruction in clinical MR imaging. This technique is estimated to lead in consistent scan time reduction. Since MRI reconstruction involves partial sampling of the k-space data, certain issues like signal losses, truncation artifacts etc. are seen in the reconstructed k-space. Inorder to address these issues in partial k-space reconstruction, the principle of phase correction is applied. Among the demerits of partial K-space acquisition includes phase errors and truncation artifacts. Inorder to address these issues different phase correction methods have been designed.This paper presents a review of the different phase correction approaches which are applied for partial fourier reconstruction of MRI while taking into account the merits and demerits of the same.**

Keywords— **partial K-space, artifacts,phase errors, phase correction , scan time**

I. INTRODUCTION

Partial k-space acquisition in MRI is usually the collection of a fraction of a full k-space data by reducing the number acquisitions required to construct an image of a given resolution. It is usually referred to reducing the scan time and the echo time of acquisition.

Inorder to address the problem of incidental phase variations in the k-space, different phase correction methods have been introduced in the partial k-space reconstruction. These phase correction methods are applied either by direct or iterative base. The conventional methods applied for phase corrections through direct approach include zero filling, conjuaagate synthesis and homodyne detection whereas iterative approach follows the POCS (Projection Onto Convex set).

The zero filling or the zero padding method performs image reconstruction by replacing the uncollected part of the k-space data i.e the readout samples with zeroes. Here the magnitude is obtained by applying a 2DFT. However this method results in a significant blurring in the phase encode direction.[1]

To address the problem of significant blurring, a conjugate synthesis approach for phase correction was proposed. Here a narrow symmetric portion of the central k-space is collected and a inverse DFT is applied to both the symmetric portion and the full k-space data .

Later convolution is performed between the conjugate of the phase of the symmetric portion with the partial image data. A conjugate symmetry of the partial image data is obtained by applying DFT to the frequency domain, finally inverse transformed to obtain a phase corrected image data.
The effects of partial k space reconstruction through these methods were found to give rise to loss of vessel signal as the vessels were too small to be resolved by the phase compensation function, producing velocity dependent phase shifts. Signal losses were found to be more prominent near the air-tissue boundaries such as the sinuses.

Homodyne reconstruction is the next step towards phase correction. This method prevented the recurrent use of transforms for generating the final reconstructed image which followed in Zero Padding and Conjugate Synthesis method that increased the processing stage. The key factor in the homodyne algorithm is to pre weight the k-space data so that when we take the real part of the image data, it corresponds to a uniform weighting in k-space.

POCS (Projection Ono Convex Sets) method focusses on the iterative application of phase correction and conjugate synthesis approach. The current k-space estimate is multiplied with the real part of the phase corrected partial k-space data and inverse transformed, this information is updated . This method is repeated for four to five iterations.

In [2] phase corrected inversion recovery MR images are produced using a regional phase correction approach. This method is also estimated to correct the phase errors without the application of a phantom data. The proposed method takes into account the phase information which is otherwise ignored in the inversion recovery based images. One of the demerits includes the user dependency in setting the thresholds of magnitude and phase coherence. The algorithm has been also applied to water-fat images and have been found to achieve good results.

In [3] Synchronous detection used in amplitude modulation of communication systems is applied in MR imaging systems in place of magnitude detection. It is found that compared to the conventional magnitude detection, synchronous detection could provide complete suppression of undesired quadrature components preserving the phase information, also preventing reduction of the Signal to Noise

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Ratio(SNR) and preserving contrast in low SNR images. Using a Homodyne demodulation reference, the incidental phase variations in MR image is eliminated.Synchronous Homodyne detection is considered to overhead magnitude detection by means of improved SNR and contrast, removal of blurred quadrature components as a result of partial K-space acquisition with simultaneous detection of water and lipid signals, and preserving of polarity in inversion-recovery signals.

In [4] a constrained imaging concept is discussed. Here three model based imaging techniques are analysed to overcome the limitations of direct application of fourier series model in MR imaging. The essential feature of the methods is that a parametric model in the form of a generalised series is superimposed on the underlying measured data or image.All the three model based imaging methods are based on the generalised series model as given by :

$$\rho(x) = \sum_{n} c(n)\varphi(n)$$

where $\varphi_n(x)$are the basis functions and $c_n(x)$ is the weighting function. The key factor that determines the success of a model based imaging method lies in the selection of the basis function $\varphi_n(x)$. The first model based imaging method is based on parametric image reconstruction in which $\varphi_n(x)$ is directly determined. This method is said to result in improved resolution and reduction of ringing artifacts. One of the limitations of this method is a need of computation requirement bringing the need of a special array processor that makes computation expensive. In the second model based method an optimal image reconstruction is carried out. A 4 to 8 fold improvement of imaging efficiency interms of temporal resolution compared to the Fourier imaging with 128 encodings is noticed here.In the third method a spatiotemporal distribution of a dynamic object is reconstructed using the basis functions which are derived from the navigator signals. This method depicts dynamic imaging by motion estimation that handles complex non rigid body motion. It is shown to have a considerable reduction in the occurrence of motion artifacts in a Fourier image.

In [5] fast reconstruction algorithms are discussed that addresses degradation in images due to field inhomogeneity. The paper analyses different types of Conjugate Phase Reconstruction (CPR) and Simulated Phase Evolution and Rewinding algorithms for inversion of the MR signal. These algorithms are further applied to spiral MRI . The results approves that for the inversion of MR transform, CPR is suggested as a viable method for the removal of off-resonance artifacts from spiral MR images. The CPR-P-r is the most appropriate algorithm suggested among the prevailing ones. The results also claims that approximate inversion of the MR transform by SPHERE is less accurate than an approximate inversion by CPR. However this maybe untrue in Cartesian MRI, as SPHERE can help to make a better use of distorted frequency maps.

In [6] different fast MR techniques such as the fast spin echo, fast gradient echo , echo planar to hybrid techniques for acquisition of short repetition and echo time are discussed. In addition the paper also suggest different fat suppression techniques in MR imaging to obtain faster images and higher Signal to Noise ratio (SNR). In fast GRE sequences, the two types of sequences discussed are Turbo Field Echo and FISP(Fast Imaging with Steady State Precession). While Turbo Field Echo uses a minimal TE and TR and low flip angle which relatively eliminates flow related artifacts, FISP applies to contrast enhanced Magnetic Resonance Angiography (MRA) of renal arteries with short TR and large flip angle. To counter the effects of susceptibility differences faced by Gradient sequences, fast Spin Echo sequences are introduced which includes RARE (Rapid Acquisition with Relaxation Enhancement) that reduces the MR scan time by reducing the RF excitations of an image , HASTE (half-Fourier single-shot turbo spin echo) a single-shot version of the TSE technique that reduces the scan time by 2 fold compared with other techniques and TGSE(Turbo Gradient Spin Echo Sequence) which is a combination of gradient and spin echo sequences. Different coil technologies discussed in the paper are Phased array coils, Endoluminal coils and Simultaneous acquisition of spatial harmonics (SMASH).

Patrice Munger et al.[7] devised a method for correction of geometric distortions in Echo Planar Imaging (EPI), based on the Conjugate Gradient algorithm which solves the EPI imaging equation. Two different approaches are incorporated here, one that solves the full four-dimensional (4-D) tensor imaging equation, and the other one is applicable when the field offsets are small, wherin a one dimensional (1 D) processing is applied to each column of the image. The Conjugate Gradient algorithm is estimated to have the best intensity homogeneity, using a minimum number of iterations typically with two number of iterations the phase correction is said to have achieved.

Samuel Fuller et al. [8] described a new technique that performs iterative decomposition of water and fat based on a echo symmetry, least squares estimation (IDEAL) method with fast spin echo imaging . The results obtained from the IDEAL fast spin echo inaging were compared with the conventional fast spin echo imaging technique. From the results the IDEAL fast spin echo imaging superimposed the fast spin echo imaging with improved diagnostic image quality and higher fluid-cartilage contrast to noise ratio. The propose method gave excellent fat suppression results in the areas of consistent failure of fat suppression in fast spin echo imaging.

In [9] two different approaches of acquiring subsampled partial fourier MRI data with multiple receiver coils has been reviewed and compared. The first approach includes Homodyne detection with Sensitivity Encoding (SENSE) like reconstruction while the second approach focusses on two

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parameter regularization in which each of the parameter constrains on the real part of the solution and the imaginary part respectively. The major difference between the two approaches is the number of symmetric lines acquired in K-space for image reconstruction which is significantly more in homodyne detection compared to the two parameter approach. From the results it is inferred that the two-parameter regularization approach allows greater control on the phase thus achieving a balance between noise amplification from the reconstructed subsampled parallel MRI data and phase artifacts from the partial-Fourier data.

In [10] different techniques for correcting intensity inhomogeneity artifact in MR imaging is proposed. The three popular modelling methods that are discussed in the paper includes a low frequency model, hypersurface model and stastical model. In low frequency model low pass filtering is applied, assuming that the intensity inhomogeneity artifact (IIH) artifacts occupies low frequency components in frequency domain. In hypersurface or surface fitting model, the IIH map is obtained by computing the parameters through the method of regression. The statistical model includes the IIH map which is derived through statistical estimation. Apart from these methods, the paper also reviews on three recently developed IIH correction methods which is the expectation maximization (EM), white matter (WM), and the N3 method. The N3 method is considered to be more popular and in use from the existing ones due to its excellent performance.

In [11] , a phase correction method for the calculation of water and fat images is proposed. This technique applies integration of phase gradients. The proposed method is estimated to have achieved reliable results compared with the phase correction method on region growing. Processing time and computational cost are a part of concern in the proposed method.

In [12] POCS method is applied to 2D partial k-space MR imaging, and the effects of different location of the k-space and the phase shift on the reconstruction quality is analysed. Here the reconstructed image is derived using the following expression:-

$$m_r(x,y) = |m_p(x,y)| \exp\{i\phi(x,y)\}$$

where $m_p(x,y)$ is the inverse fourier transform of the 2D partial k-space and $\phi(x,y)$ is the phase of the image.

The k-space here was estimated as:

$$M_R(K_x,K_y) = DFT\{m_r(x,y)\}$$

It is observed that the errors generated due to POCS is comparatively lesser then the Zero Filling method since it recovers the symmetric portion of the original 2D partial K-space . While the Zero Filling approach focusses on the center of the k-space , POCS allows for an optimal choice of location of the partial k-space thus keeping intoaccount for both high frequency and low frequency information.

Antoine Abche et al. [13] devised a modified Homodyne approach that segments the MR images using an active contour segmentation approach. Unlike the conventional Homodyne approach that reconstructs the image from the full K-space , the modified approach focusses on partial K-space reconstruction. The evaluation of the modified Homodyne approach is carried by means of a performance test and Root Mean Square. The results obtained from the proposed method is also compared with the Zero Filling method, POCS, Homodyne approach, and Conjugate Synthesis approach. From the results the modified approach is estimated to have better visualization of structural details due to improved image quality compared to the other approaches.

Jianhua Luo et al. [14] developed a new technique for removel of truncation artefacts in MR image by recovering the missing K-space or spectral data. The proposed method is a This paper proposes a novel layer deconvolution spectral (LDS) analysis method based on a sparse representation of the difference image of the input image, and estimating the parameters of the sparse representation from the Zero Filled (ZF) reconstructed image thus recovering the missing k-space or spectral data. The algorithm has been applied to both the simulated data and to real MR multispectral data, and the results obtained from both the data determines the efficacy of the method in terms of preserving the image quality and better performance compared to other conventional techniques.

In [15] a sparsity driven approach for joint Synthetic Aperture Radar (SAR) imaging and phase error corrections, is formulated for imaging fields with sparse representation.The proposed method includes an iterative algorithm, where each iteration of which consists of consecutive steps of image formation and model error correction. The results discovers that the proposed method displays better phase error estimation, finer visualization through noise and artifact suppression along with improved resolution.

In [16] an iterative prediction method is developed that introduces an improved low-resolution phase approximation for phase correction. This method is derived using the boxcar representation in the spatial domain and the signal space representation of its frequency weighted k-space.The proposed predictor method uses Finite Impulse Response (FIR) filters that addresses to the problems of phase errors and truncation arifacts which arise as a result of truncation in the conjugate asymmetric k-space. The predetermined set of k-space samples are filled iteratively by the one step predictor using an updated set of filter coefficients. It has been estimated that the low resolution phase approximation derived from the symmetric portion of predicted k-space has been able to restore the portions of the information that were undetermined in a homodyne phase corrected image

In[17] signal acquisition in MR imaging using multiple k-space scans is discussed . By averaging the signals of these

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scans, it is estimated that there is a considerable reduction in the artifacts that occur during signal acquisition such as the white Gaussian noise and the motion artifacts with improvement in the Signal to Noise ratio (SNR). Further to reduce the scan time, partial K-space scans are acquired using reconstruction algorithms. By performing signal averaging, Signal to Noise ratio (SNR) is also improved. The paper reviews about the conventional Compressed Sensing (CS) based reconstruction technique.The proposed method reconstructs the MR image from multiple partially sampled K-space scans by exploiting its rank deficiency through the nuclear norm minimization concept .The method is compared with the Compressed Sensing (CS) based reconstruction technique wherein the reconstruction accuracy is found to be the same. However in terms of magnitude the proposed technique is considered to be five to ten times faster.

In [18] reviews different formulations of iterative methods, for image reconstruction from non-Cartesian K-space samples. The different formulations included in this aspect are continuous-continuous, continuous-discrete, discrete-discrete, least square reconstruction , regularized least squares method and Conjugate Gradient algorithm. One of the merits of these methods include the density compensation which is not required. Longer time of computation is a demerit of these iterative methods.

II. DISCUSSION

This paper discussed on different phase correction methods for partial K-space sampling of MRI data. While most methods claims on improved results in terms of image quality, scan time reduction, Signal to Noise ratio (SNR), it is a note of concern whether these algorithms can be applicable to work on all the type of datasets. The drawbacks of the conventional methods can be overcome by incorporating optimum filters such as the modified homodyne approach or fast imaging methods that has the ability to overcome the phase errors and truncation artifacts while improving the image quality at the same time.

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