Partial Fourier Technique for Image Reconstruction in MRI

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Abstract : This paper proposes a Homodyne reconstruction algorithm to improve the quality of the MRI image. In this technique, the complete reconstruction of MRI image is achieved using 60% of the input k-space acquired from the magnet. Homodyne reconstruction technique has been applied to the detection of low SNR images, reconstruction of partial k-space images and preservation of polarity in inversion recovery images. Various evaluative parameters were calculated for the reconstructed image and analysed against the image reconstructed using full k-space.

***Index Terms* – MRI, K-space, Partial Fourier Technique, Image reconstruction.**

I. INTRODUCTION

MRI is popularly used technique which generates detailed image of tissues and organs of human body in presence of magnetic field and radio waves instead of using X-rays in CT scan. It takes about half an hour to scan patient's body inside a magnetic resonance imaging (MRI) machine, as doctors look for any signs of injury or disease. That is quite long time for someone to remain still inside the scanner-especially pediatric, claustrophobic or very ill patient. The longer the patient is in the scanner, the more likely they are to move around and affect image quality. The Faster we can image, the more patients we can do. Speed of MR imaging is determined by the rates of data acquisition and image processing. Literature is filled with MRI reconstruction technique to visualize the collected information [1]. Discrete Fourier Transform (DFT) is most effective method for reconstruction of images acquired by MRI. Signals are sampled on a Cartesian grid in spatial-frequency domain (k-space) and Fast Fourier transform (FFT) is applied to reconstruct the desired image. K-space is an array of numbers where each number represents spatial frequencies in the MR signal. It is a grid of raw data in the form of (k_x, k_y) which is directly obtained from a MR signal. MR image and k-space contain identical data. The cells of k-space are displayed using rectangular grid with principal axes k_x and k_y, where k_x is the horizontal axis and k_y is the vertical axis. These 3axes represent spatial frequency rather than position.

In Partial Fourier Technique data from half of the k-space is used to generate entire image, some of the information in k-space is redundant. There should not be any phase error during collection of data; k-space possesses a peculiar mirrored property known as conjugate symmetry. In the following figure consider there are two points P and Q, located diagonally from each other across origin of k-space. Let us consider Q is complex conjugate of P, if P is $a + bi$ then Q can be defined as $a - bi$. Conjugate Symmetry is shown in following figure, to exist when Fourier transform is performed on real number valued function. The conjugate symmetric points represent corresponding data acquired on rising and trailing edges of two echoes obtain with opposite phase encoding space. Practical results of conjugate symmetry is that only half of the k-space data is need to be collected and other half is estimated. This phenomenon leads to reduction in imaging time or minimize echo time or both. There are two types of Partial Fourier Technique viz. read conjugate symmetry and phase conjugate symmetry.

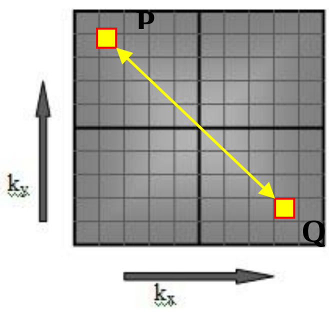


Fig.1: Conjugate Symmetry in K-space

In read conjugate symmetry data in one half of the k-space is used to estimate data in other half. The direction of symmetry is in read out i.e. phase encoding direction (horizontal direction). In this data from right half of the k-space is acquired to estimate data in left half. The full number of phase encoding steps are still require in read conjugate symmetry so there is no direct time savings. In phase conjugate symmetry data from top half of the k-space is used to estimate data in bottom half of k-space. This technique allows one to acquire data using only half the normal number of phase encoding steps. Thus potentially reducing imaging time as much as 50%. In practice, time saving is closer to 40%. It is also known as half Fourier, half scan or asymmetric Fourier transform.

II. METHODOLOGY

Current popular method for partial Fourier reconstruction of MR images is Homodyne reconstruction. This method includes sequential application of two filters to acquired k-space data. First is the high pass filter which doubles the amplitude then discards the imaginary part after Fourier transform. The second filter is low pass filter which creates correction image from small set of data acquired symmetrically around centre oh k-space. The phase of this correction image is subtracted from phase of high pass image before discarding imaginary part. The method is based on the decomposition of frequency space into low frequency components and high boost frequency components.

In communications, the use of envelop detection is unwanted or results in loss of signal for numerous cases in amplitude modulation (AM) systems. Given some general amplitude modulated signal [2]

$$x_c(t) = [x_i(t) + n_i(t)]\cos\omega_c t + [x_q(t) + n_q(t)]\sin\omega_c t$$

Where

$x_i(t)$- Desired and in-phase signal component
$x_q(t)$- Quadrature signal component
$n_i(t)$- In phase noise component
$n_q(t)$- Quadrature noise component

The detected signal from envelop detector is

$$x_M(t) = \sqrt{(x_i(t) + n_i(t))^2 + (x_q(t) + n_q(t))^2}$$

And if the following conditions are satisfied

$$x_i(t) + n_i(t) > 0$$

$$x_q(t) = 0$$

$$x_i{}^2(t) \gg \sigma^2$$

The detected signal reduces to

$$x_M(t) \approx x_i(t) + n_i(t)$$

If the carrier $\cos\omega_c t$ can be obtained, then a synchronous detector can be used

$$x_S(t) = LPF\{x_C(t).2\cos(\omega_c t)\}$$
$$= x_i(t) + n_i(t)$$

Where LPF {.} is a low pass filtering function and with no restrictions on the signals or noise.
Similarly, the complex image acquired in an MR can be given as

$$I_c(x,y) = \left[(m_i(x,y) + n_i(x,y)) + i\left(m_q(x,y) + n_q(x,y)\right)\right]e^{-i\emptyset(x,y)}$$

Where
$m_i(x,y)$Desired and in-phase signal
$m_q(x,y)$Signal in quadrature to the desired signal
$n_i(x,y)$In-phasenoise component
$n_q(x,y)$ Quadrature noise component
$\emptyset(x,y)$ Incidental and uncontrollable phase modulation

The detected signal from an envelope detector is

$$I_M(x,y) = \sqrt{(m_i(x,y) + n_i(x,y))^2 + \left(m_q(x,y) + n_q(x,y)\right)^2}$$

This can be reduced to

$$I_M(x,y) \approx m_i(x,y) + n_i(x,y)$$

When the following conditions are satisfied

$$m_i(x,y) + n_i(x,y) > 0$$

$$m_q(x,y) = 0$$

$$m_i{}^2(x,y) \gg \sigma^2$$

In most of the MR imaging cases the above conditions are satisfied, but in those where the above conditions fail and the incidental phase can be determined, then a synchronous detector can be used to modulate the image [2].

$$I_s(x,y) = real\left\{I_c(x,y)e^{-i\emptyset(x,y)}\right\}$$

$$= x_i(t) + n_i(t)$$

Synchronous detection implementation and results are explained throughout this paper.

III. PROPOSED HOMODYNE RECONSTRUCTION ALGORITHM

The input to the proposed homodyne reconstruction model is a 60% reduced k-space. This k-space consists of 154 frequency encoded lines and 256 phase encoded lines. Hence a matrix of 154*256 is taken as input to the reconstruction model. The proposed model is represented and shown below with a block diagram of image reconstruction and post processing techniques. The block diagram explains the proposed technique. The complete illustration of the proposed homodyne reconstruction model is given the block diagram shown in fig.1.

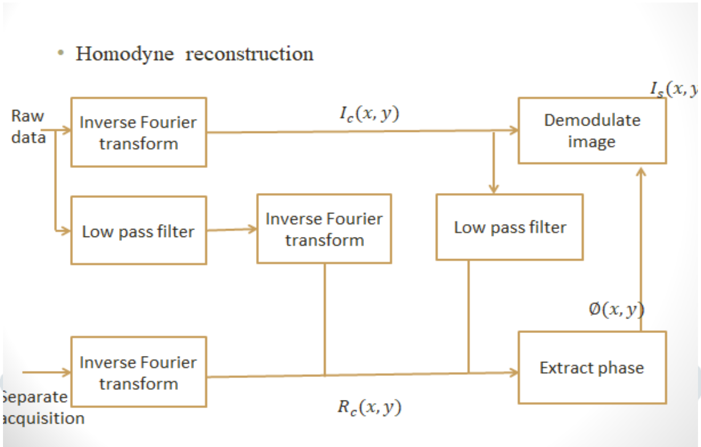


Fig.2: Block diagram of proposed Homodyne algorithm

3.1 Algorithm for Homodyne reconstruction:

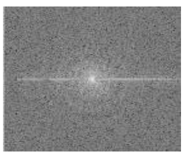
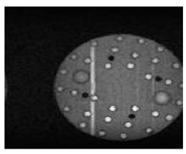
i. The phase estimate p*(x,y) and $\emptyset(x,y)$ need to be calculated. Where p*(x,y) is multiplied with image $m_{pk}(x,y)$ and weighting function $W(k_y)$ which gives the phase corrected imgae.
ii. Apply fourier transform to this phase corrected data. It obtains phase corrected partial k-space data. In this algorithm, $m_s(x,y)$ is used for the phase correction.
iii. Apply conjugate symmetry on the phase corrected to get symmetric k-space data.
iv. Apply inverse fourier transform on the symmetric data set to get required image

3.2 Algorithm for Image reconstruction:

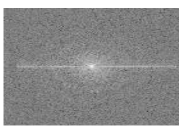
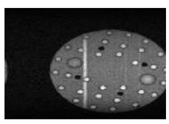
i. Read data header information: Load raw information about the MRI data file. It is a text file containing details about Offset, Data size, K_x coordinate, K_y coordinate etc.
ii. Read and process the k-space information
iii. IFFT in K_x and K_y direction
iv. IFFT shift and image display
v. Processing the above steps on the processor system of ZC706
vi. Verifying the results by comparing the image obtained after reconstruction against the reconstructed inage of complete k-space.

IV. RESULTS AND DISCUSSION

The proposed scheme is evaluated and validated bycalculating the key performance parameters of partial reconstructed image with the ideal scenario reconstruction. CalculatedMSE, PSNR, Acquisition time(T_A) and Acceleration factor (R)afterpartial k-space reconstruction and complete k-space reconstruction are identical to each other hence perceptibility and robustness of image of proposed technique is increased.Fig. 3(a) shows the completek-space acquired from a single coil. 3(b) is the reconstruction of image from single coil k-space. Fig. 3(cshows the complete k-space acquired from a single coil. and fig. 3(d) is the reconstruction of image from single coil k-space.

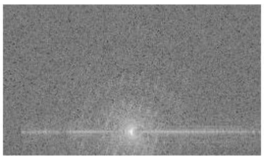
(a) K-Space image of coil 1 (b)Reconstructed image

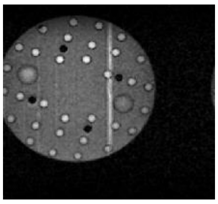
(c) K-Space image of coil 2 (d)Reconstructed Image

Fig. 3: Full k-space reconstruction

Fig 4 depicts the reconstruction performed using partial k-space. Fig 4(a) shows the partial k-space used for reconstructing the final image and Fig 4(b) shows the reconstructed image obtained.



(a) Partial k-Space image



(b) Reconstructed image

Fig 4 Homodyne reconstruction technique

The calculated evaluative parameters are represented in tabular for in Table 1.

Table1. Performance evaluation of the proposed algorithm

No	Parameters	Value	Remarks
1	MSE	0.000008	Minute MSE observed
2	PSNR	69.4dB	Inverse of the MSE, lower the error, higher the PSNR
3	Correlation	0.9927	High similarity factor obtained
4	Acquisition time	40% reduction	Reduction in T_A by 40% was observed due to the collection of partial k-space
5	Acceleration factor	1.66	

The above table shows the evaluation parameters obtained from the image observed after reconstruction. These results verify and authenticate that the proposed technique is robust and imperceptible.

IV. Conclusion

In this work, an MRI reconstruction approach is proposed. The approach is based on homodyne detector for partial k-space reconstruction. In other words, it is based on the decomposition of the frequency space into low frequency components and high boost frequency components. The evaluative parameters calculated gives a PSNR of 69.4dB with a similarity index of 0.997. This technique can be implemented on the hardware conveniently on FPGA in the future for multiple coil images, and performing sum of squares method will provide an image of higher quality.

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