A SURVEY ON PARALLEL IMAGING IN MAGNETIC RESONANCE IMAGING

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Abstract: Parallel imaging is a vigorous method to accelerate the acquisition of magnetic resonance imaging (MRI) data. Parallel imaging works by collecting reduced data set for image reconstruction with the help of receiver coils array. The undersampling of data creates aliased image, to produce aliasing free image parallel imaging techniques can be used. The applications of parallel imaging is to reduced the acquisition time, improve the spatial resolution or both. In this paper basic physics for magnetic resonance imaging (MRI) is given also the structure of MRI machine is described. The focus of the paper is to introduce the parallel imaging techniques in MRI such as Generalized Autocalibrating Partial Parallel Acquisition, Sensitivity Encoding and Partially parallel Imaging with Local sensitivities are described.

***Index Terms* -** MRI, Parallel Imaging, SENSE, GRAPPA

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. With the help of MRI images doctor can get very small details of patient's body with the help of Nuclear Magnetic Response (NMR). Human body is made up of 70% of water i.e. H_2O. Hydrogen nucleus is form by combination of single proton and no neutron, as a spinning charge particle this produces a magnetic field known as magnetic moment. Normally the protons are oriented randomly after the application of magnetic field the protons get aligned parallel or anti parallel to the magnetic field. MRI uses the magnetic properties of hydrogen atoms to produce images. The components of MRI system are primary magnet, gradient magnet, radio frequency (RF) coils and a computer system. In the presence of primary magnetic field the hydrogen atoms body tissues get aligned parallel or anti parallel to the magnetic field. The atoms which are parallel to the magnetic field are low energy state atoms and the ones which are anti parallel are high energy state protons. A greater proportion aligns parallel than anti parallel to primary magnetic field. The gradient coils are placed inside the primary magnet and are used to generate secondary magnetic field. They are arranged in opposite to each other so that they can produce positive and negative pulse. MRI has capacity to image directionally in x, y and z axis due to the arrangement of gradient coils. There are three gradients named according to the direction they work. The z gradient runs along long axis to produce axial images, the y gradient runs along the vertical axes to produce coronal images and the x axis runs along horizontal axis to produce sagittal images. The radio frequency coils or RF coils are used to transmit the radio frequency signal and to receive the signal in MRI. RF coils are available in various designs suitable for body part of which image is to be taken. The computer systems are used to store the RF signal where it is converted to digital form. The signal representing the imaged body part is stored in the temporary image space or k-space.

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 ($k_{x,}$ ky) which is directly obtained from a MR signal. The values in the k-space correspond to spatial frequency of image. Rows near centre of k-space grid corresponds to low-order phase encode steps and row near top and bottom corresponds to higher order phase encoding. Due to application of the gradients for phase and frequency encoding, the MR signal is in Fourier like format.

Parallel imaging uses the known placement and sensitivities of receiver coils to get the spatial location of MR signal. Due to this coils allow reduction in phase encoding steps during image acquisition which reduces the scan time. Parallel imaging is a reconstruction technique which can be used to reconstruct undersampled data from any type of pulse sequence. The methods for parallel imaging are Partially Parallel Imaging with Local Sensitivities (PILS), Sensitivity Encoding (SENSE) and Generalized Autocalibrating Partial Parallel Acquisition (GRAPPA)

II. PARAMETERS

Following parameters can be consider to check the image quality.

2.1 Mean Square Error (MSE)

It is the cumulative squares error between the reconstructed image to the original image. Low value of MSE indicates better system. It is calculated by mathematical expression,

$$MSE = \frac{1}{MN}\sum_{y=1}^{M}\sum_{x=1}^{N}[I1(x,y) - I2(x,y)]^2$$

2.2 Correlation

It is the measure of similarities between reconstructed image and reference image the maximum value of correlation is one. The correlation is calculated with the help of,

$$Correlation\ factor = \frac{\sum_i (x_i - x_m)(y_i - y_m)}{\sqrt{\sum_i (x_i - x_m)^2}\ \sqrt{\sum_i (y_i - y_m)^2}}$$

2.3 Peak Signal to Noise Ratio (PSNR)

PSNR is the measure of peak error. The maximum value of PSNR indicates the better results. Peak Signal to Noise Ratio is calculated as,

$$PSNR = 10 \log_{10} \frac{max^2}{MSE}$$

2.4 Acceleration factor (R)

Acceleration factor also known as reduction factor is the ratio of amount of fully sampled k-space data to the amount of undersampled k-space data. It is calculated by using,

$$R = \frac{(Amount\ of\ k - space\ data\ for\ fully\ sampled\ image}{Amount\ collected\ in\ accelerated\ acquisition}$$

2.5 Acquisition time

Total acquisition time is given by the product of repetition time and number of phase encoding lines. Repetition time helps to determine contrast in the image and phase encoding lines determine the resolution of image in phase encoding direction. Acquisition time is given by,

$$T_A = T_R \times N_{PE}$$

Where,

$T_A = Acquisition\ time$

$T_R = Repitation\ time$

$N_{PE} = Number\ of\ phase\ encodes$

III. PILS

Field of view (FOV) is the distance over which MR image is acquired or displayed. During acquisition smaller FOV images are acquired parallel to elements in array. The PILS takes the concept of reduced FOV acquisition in single coil and apply it to the array acquisition. Different coils in an array have different localized sensitivity. Each coil has sensitivity in some region and remaining region consists of zeros. Each coil will contain the information of different region of object. Periodically repeated images are formed due to accelerated acquisition. As the reduced FOV is larger than sensitivity region the position of sub image is lost and appear separated in the full FOV. With the help of exact position of each coil in array, the corresponding image at correct position is extracted. When all such sub images are obtained, they are combined to form full FOV image.

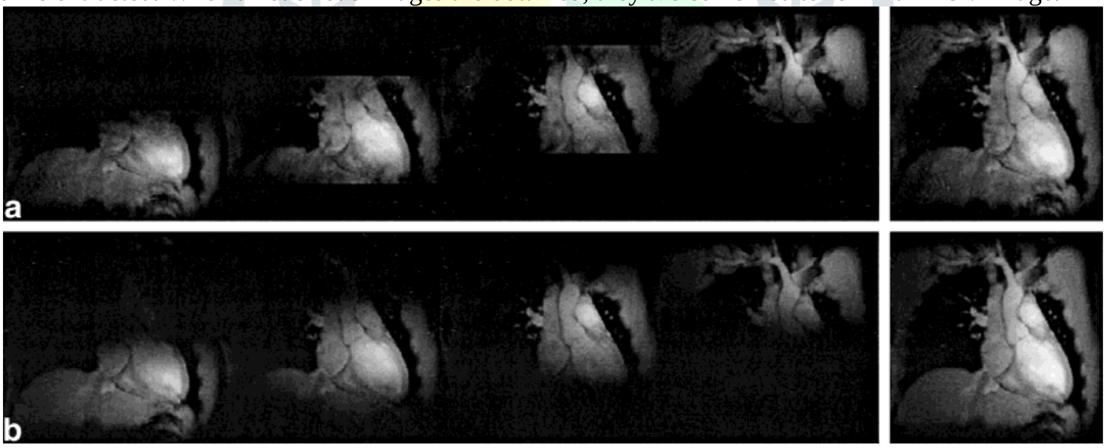

Fig 1 a: PILS reconstruction. b: Corresponding fully gradient reference images. The PILS image in a have comparable quality to those acquired in b[2]

It is Partial Parallel Acquisition imaging technique which is easy to implement in practice, easy to understand, requires minimal a priori information about the coil array and provide optimal SNR at all acceleration factors [2]. Small FOV images are acquired for each coil using the knowledge of position in bands. They are then positioned at proper location in image sized of full FOV.the result is then combined to get final image.

IV. SENSE

It is form of image domain parallel imaging. The known sensitivities of the coils are used to reconstruct the images. It can be use for cardiac and head images. The sensitivity maps are acquired during the prescan. There are basic four steps in SENSE. The coil sensitivities are obtained during the prescan (a separate acquisition before actual image scan begins). The undersampled k-space data is acquired with the help of accelerated scan. Small FOV images are constructed for each coil. When all partial images are available, they are combined by matrix inversion method. The most important step in sense is to measure the coil sensitivities correctly. Low resolution images are obtained from each coil; these images are divided by low resolution body coil image to obtain normalized form. The coil sensitivity maps are obtain by applying filtering, point estimation on data. These maps quantify the relative weighting of signals from different points of origin within the reception area of coil.

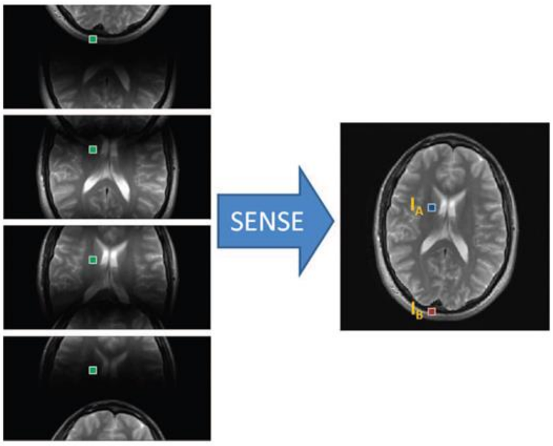

Fig2: Image reconstruction with SENSE[1]

V. GRAPPA

There are four major steps in GRAPPA viz. Data acquisition, estimation of missing line, generate individual coil images and combine the images. During data acquisition some phase encoding lines are left out, GRAPPA is used to create these left out lines of k-space. After the reconstruction of full k-space the Fourier transform is applied to get the image. The data which is available is used to get the missing lines. MR signal is digitized and demodulated to fill the k-space. Due to multiple phase encoding k-space lines got missed. The centre line of the k-space data is fully sampled and contains autocalibration region (ACS). Extra ACS lines are used to reconstruct image hence known as Autocalibrating. Appropriate combination of acquired points is used to estimate missing points. The data from ACS region is used to estimate weighting factors. Weighting factor represents how each coil distorts, smears and displaces spatial frequencies. Global weighting factors are combined with small region of local data (kernel) to find out missing k points. The kernel describes number source point to obtain fully sampled k-space. Missing data is estimated with the help of weighting factors and known data. Target points can be found by sliding the kernel throughout the ACS region. The mathematical relation between source and target points in ACS region is determine using the weight set. Once the weights are estimated the kernel is moved to under sampled region to fill the missing lines. After the availability of the full k-space data, individual coil images are generated by applying Fourier transform. When we have individual coil images then they are combined by using sum of square method to get one image.

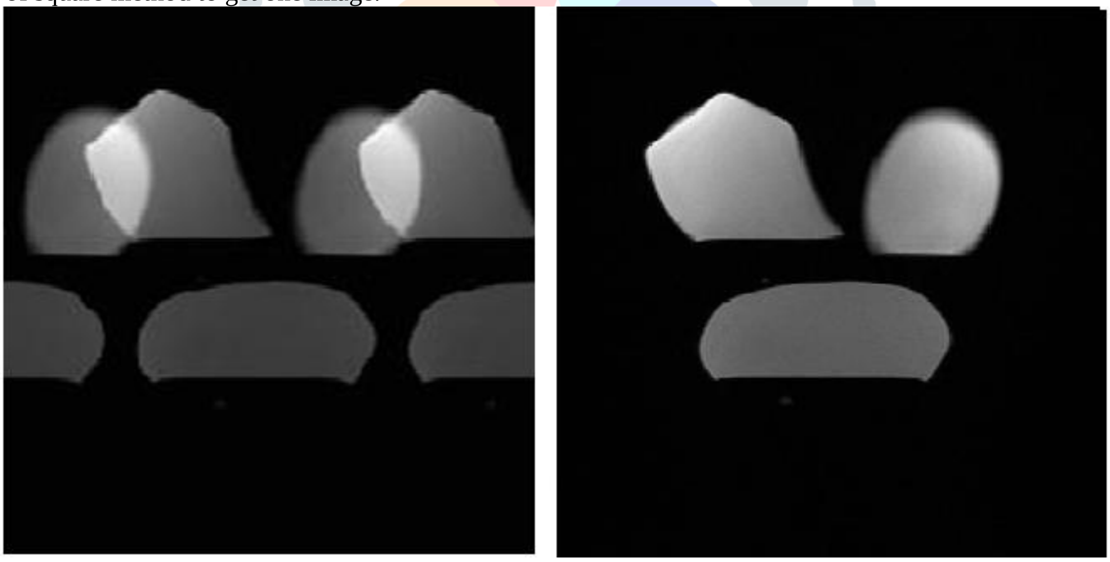

Fig 3: Aliased image obtain from undersampling and aliased free image after GRAPPA

The benefit of the autocalibrating process used in GRAPPA is that, besides using the ACS lines to determine the coil weighting factors, these extra lines can be integrated directly into the final image reconstruction to improve image quality[1].

VI. CONCLUSION

In this review three parallel imaging techniques are discussed. The time for collecting k-space data can be shorten by undersampling the k-space in phase encoding direction. Parallel imaging takes the help of array of coils and specialized algorithms to create full k-space resulting in the full FOV image. PILS requires minimal information about the coil array to obtain image. The incorporation of simple coil parameters into a localized Fourier transform allows reconstruction of full FOV images. SENSE uses the knowledge of coil sensitivity maps to perform the image reconstruction. GRPPA uses autocalibration signal and kernel in k-space to obtain aliased free images. Parallel imaging can be used to reduce acquisition time, improve temporal and spatial resolution and for betterment of image quality.

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