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Super Resolution of the Magnetic Resonance Imaging Reconstruction

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***Abstract*— The medical images after reconstruction have some defects, and the enlargement the image to the desired magnification factor causes the defect to be appeared again and in dense forms and causing the image is not suitable for transmission and displaying on the HDTV, or other high definition devices. We summarize the super resolution process in the denoising and debluring and remove aliasing and crosstalk using adaptive noise filter,also perform registration with decreasing aliasing effect, and remove the crosstalk by using 'intensity interpolation' of the MRI slices .this is achieved by simulation blurring (Gaussian),noise(salt &pepper), aliasing for the medical image (type "shepp-logan", and MRI slices originally reconstructed).**

***Keywords*: MRI, super resolution, adaptive median filter, medical image, aliasing, salt and pepper.**

I. Introduction

Medical image modalities like CT –scan and MRI scan produce reconstructed image which is different in the model of reconstruction, the MRI reconstruction steps include variable factors controlling the types of MRI image, depending on the tissue of the organ proton density ,also the calibration of the dephasing process during the signals sequence produce different images like, spin echo, gradient echo image, which are used as the process of removing the decaying in the acquisition RF signals to achieve repetition as fast as possible and construct the image with fast scanning.

II. MRI reconstruction

So the mechanics of acquisitions of all the signals needed for reconstruction depends on the RF signals profiles see Fig.1 which is repeated until complete signals from all the tissues of the plane is received. The MRI signal is mix of RF waves in the varieties of amplitudes ,frequencies and phases and containing spatial information and the signal is digitized where a raw data are written into a data matrix called k-space[1] which is converted to the image using Fourier Transform .

The k-spaces are then sampled where some of the most popular trajectories types is used such as spiral and Cartesian trajectories. The output k-space is the raw data which is input to the Fourier transform and get the final output spatial image from frequency encoded image .The k-space is not complete and partial k-space is input to the reconstruction algorithm to obtain the full k-space which has different calculations according to the algorithm of reconstruction used.

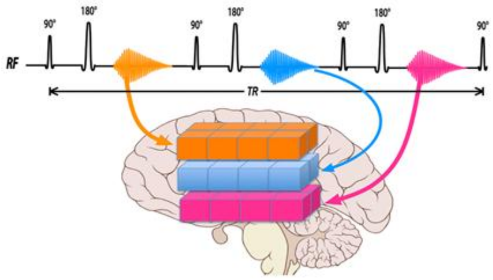

Fig. 1 MRI pulses sequences

III. MRI super resolution:

MRI reconstruction can be done with gridding method, where the gridding method applied to phase encode direction in the 2DFT, or in both directions in spiral imaging. The aliasing artifacts from the gridding method avoided by putting the density of the grid higher than the highest sampling density of the actual trajectory, and the convolutional kernel must be made wide to cover the unsampled regions and to obtain an estimate of values of all grid points. But using variable density trajectories results in lower SNR in images.

The high frequency component contains little energy, under sampling them will not contribute sever aliasing artifacts, and the LF artifacts can be avoided by sampling the central k-space region sufficiently, and one can use a variable density trajectory, which sufficiently samples the central k-space region and samples the outer k-space region with lower density to achieve HR and minimal aliasing artifacts simultaneously without increasing the total scan time.

The k-space origin is determined first by the actual object size to eliminate LF aliasing artifacts, the sampling density is then gradually decreased as the trajectory moves away from the origin, and if the sampling density decreases too quickly ,then the trajectory covers a greater extent in k-space and results in higher spatial resolution but the overall image is compromised by more severe aliasing artifacts[2]for a 2DFT trajectory ,the variable density sampling method can be applied.

IV. Medical image defects:

The pre-processing of medical image type CT – scan reconstructed image [3]and MRI image is to remove the noise and blurring of each low resolution image by treated the noise as external process out of super resolution process, we must achieve some processing of removing the noise and blurring from medical image , to give our search more robust to any noise before any super resolution reconstruction

A. Blurring effect

We began here with blurring on image and we choose the deconvolution using 'Wiener filter algorithm' with known point spread function(PSF) .We test that the effect of 'deconwnr' in the case of Pre-processing super resolution is not the same in the case of post- processing we compare the result on shepp-logan (512) which is used in medical images analyses, has been down sampled to (256) ,with anti-aliased filter on the image before down sampling to simulate the LR ,and Gaussian blurring function are convolved with LR image , the size of PSF is (16) and variance of (2),where the result stated that the super resolution after debluring is more than in PSNR that the debluring of super resolution image as in the figures below:

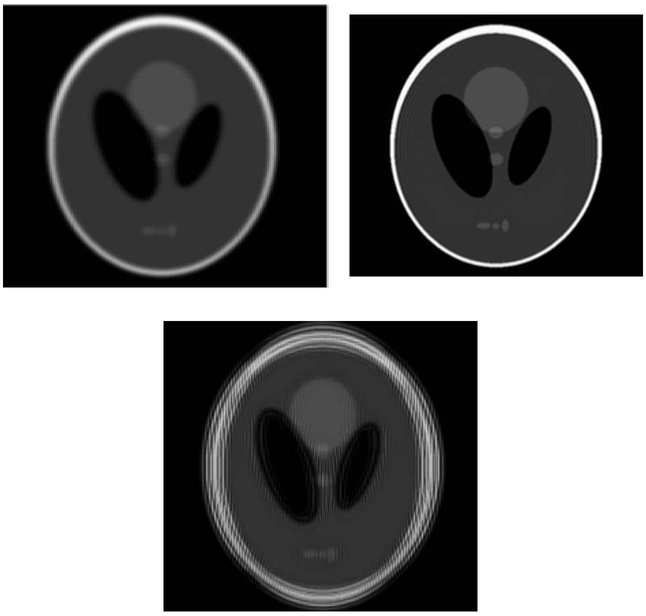

Fig. 2 Deblurring on image(a)blurring with Gaussian function(PSF)(b) deblurring then super resolution (c) super resolution then deblurring (worst case)

B. Noise effect

The noise in the LR images which is the important side , must be treated before the interpolation which the interpolation generate more noisy sample in the output image if it is not cleared exactly before that ,so the median filter which is used as filter for remove noise with edge preserving and noise type is ('Salt &Pepper') noise and the median filter size range between the [3~9,3~9] in odd values are not robust to the high Pa and Pb (noise density of salt and pepper noise). where the built in function in matlab 2017b, has been used for 0.2 or less, so adaptive median [4]filter program has been written in matlab and we tested it with the various noise density from 0.1 to 0.5 and it gives more fine result than the median filter size [3 3] which is gives the closet result to the adaptive median filter and the noise density and denoising using adaptive median filter are listed in the figures below.

If we repeat the adaptive median filter from 1~2 iteration, the output noise density will be improved and it is useful in a case of 0.5 noise density. The PSNR between 6~14, due to the noisy image has been taken as the reference image

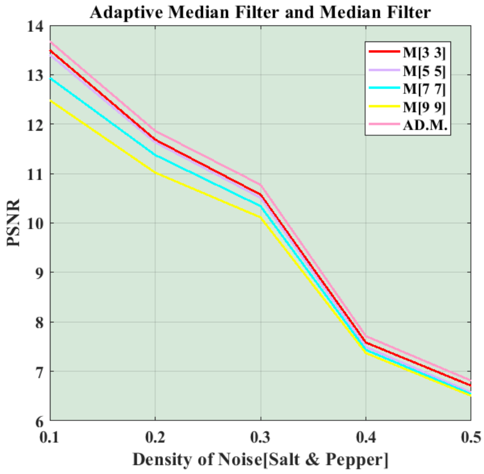

Fig. 3 Comparison adaptive median (AD.M) filter with classical median filter in PSNR

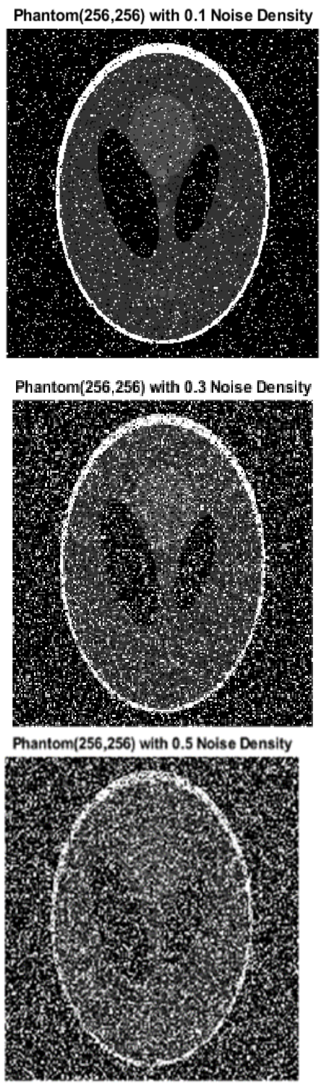

Fig. 4 Noisy images with (a)0.1(b)0.3(c)0.5

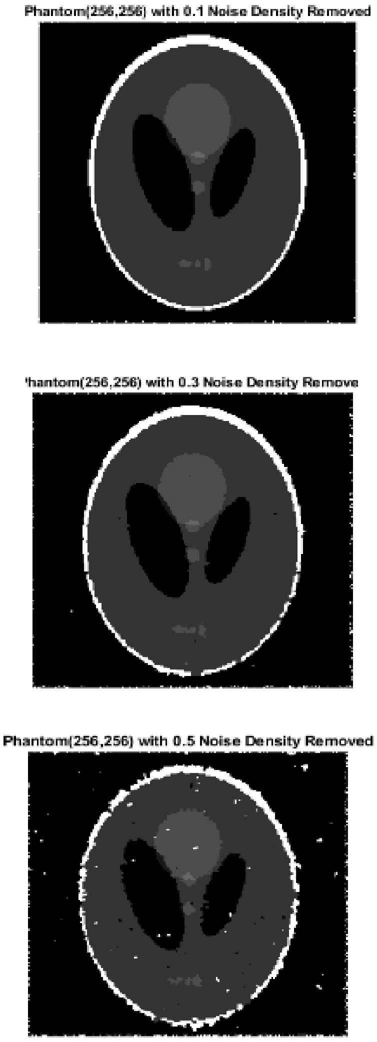

Fig.5 Adaptive median filtering (a) 0.1(b) 0.3(c) 0.5

C. Aliasing effect:

Image alignment and stacking are often used to increase the signal to noise ratio for faint objects. the computer performs transformations on one image to make major features align with a second or multiple images The registration is process for converting multi low resolution sub pixel shifted images to single image ,because it gives the information in all images into single image for analysis and diagnostics, with enhanced results, depending on the percentage of edge pixels in the image, Also the problem of fine registration depends on the aliased of the image, more aliasing means poor registration and the antialiasing filter remove the aliasing, but increase the blurred of the image which means fine registration with low resolution

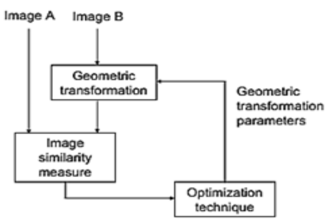

Fig. 6 Image registration

Figure 4 clarify the general registration process, where there are various transformation types, which must be used to give the accurate aligning image with the other image comes from different times or different modality, we take here the transformation, as below:

1- *Rigid transformations:*the rigid transformations include rotations , translations , reflections , or their combination. Any object will keep the same shape and size after a proper rigid transformation. All rigid transformations are examples of affine
2- *Affine transformations*: the affine transformations in 2D can be represented as linear transformations in 3D.

And the following algorithms has used to perform the registration process in our search:

1- Phase correlation method
2- Intensity registration method
3- Non - rigid registration method

Using the reconstructed image 'shepp-logan' reconstructed from the Filtered Back Projection algorithm [3] ,where LR images are generated by shifted it, so the sub pixel shift must be used in this operation. We have dealed with three types of transformations and register them with the result in the following cases:

Case 1

Aliasing free image: using 'anti-aliased filter' using the kernel = [1 4 16 4 1]/16, before down sampling process, in which the aliasing effect the fine registration for the following transformations types:

TABLE 1 CASE 1

Transformation type and other process	SSIM	Time	Registration method
anti-aliased ,rotation ,down sampling	**0.984**	1.16	phase correlation
anti-aliased ,translation , down sampling	**0.988**	**0.23**	phase correlation
anti-aliased ,non-rigid, down sampling	0.951	2.70	intensity registration

Case 2:

Aliasing image: we simulate the aliasing image using 'bicubic interpolation' by down sampled the image only, and using the registration approaches above to fit the best alignment, there is no fine registration appear:

TABLE 2 CASE 2

Transformation type and other process	SSIM	Time	Registration method
Rotation , down sampling	**0.842**	1.20	Rigid registration
Translation , down Sampling	**0.856**	**0.36**	Intensity registration
Non-rigid , down sampling	0.462	0.69	Intensity registration

Case 3:

The filter kernel above has used, to remove the aliased signals after down sampling, which aliasing produce less quality registration.

TABLE 3 CASE 3

Transformation type and other process	SSIM	Time	Registration method
Rotation, down sampling ,filter	**0.996**	1.11	Non-rigid
Translation ,down Sampling , filter	**0.992**	1.18	Non -rigid
Non rigid, down Sampling, filter	0.417	**0.23**	Intensity registration

We infer from results above the registration with the non-rigid transformation is lowest accuracy than other transformation ,the non-aliased images using antialiasing filter are registered in more quality than other aliased image, the aliasing are removed before the down sampled image using 'anti-aliased filter' and the result are more accurate in registration ,but it is more blurred in super resolution. Where the SSIM results stated that the registration is improved in the case 3, raw 1and 2, but the anti-aliased filter before down sampling will remove more information from the image rather than using it after the down sampling process.

D. Crosstalk effects:

The resolution of MRI slices is not homogenous, and our working in the medical image type, MRI reconstruction, in which the high resolution of medical image reconstruction is in the in-plane which may produce good or worse slices reconstruction .The number of slices mostly from 28 to128 slices for slice thickness approximately 5 mm to 0.5 mm, which is alter the signal to noise ratio for each slice thickness. The spaces between the slices called 'gap' which is percent value of the slice thickness.

Fig. 7 Slices reconstruction in two acquisitions to avoid crosstalk

To make the interpolation contribute in the reconstruction of the interslices, the time of reconstruction is depending on the interpolation type, and the slices are obtained from enter "load mri" in matlab 2017b in the command prompt, which is 28 slices in the slice select direction (z-direction).

The Cross-Talk between slices affect the contrast of image slice reconstruction , and this avoided by setting the gap between slices [5] ,the gap is used to prevent the excitation of the contiguous slices during the excitation of one slice .

The Cross-Talk increased in the case of small gab scanning and leads to more artifact on the image, so the scanning must be on the entire volume, and another slices reconstructed without additional scanning. The relationship between slice thickness h (inversely to the number of slices), SNR, and acquisition time, Tacq is given by [2]

$$SNR \propto h\sqrt{Tacq} \qquad (3)$$

The SNR value is very important for image quality appearance and to make the reconstructed intermediate slices as the original slices SNR if we use the interpolation between the slices the result depend on the SNR of the original slices and the gab thickness between slices (which is used to reduce Cross-Talk) .In this experiment we interpolate the even slices and fix the odd slices.

In the following table we have noted the super resolution does not construct different slices properties in the correlation values which is not altered less than 0.8 and the other result gives steady state values.

The reconstructed slices with the original slices is as follows :

TABLE 4 SLICES RECONSTRUCTION

SLICES	SSIM VAL	CORR	MSE	PSNRDB	PSNR VAL
2	0.761871	0.886338	0.003805	31.86159	24.19533
4	0.728362	0.843103	0.004361	31.61388	23.60335
6	0.752929	0.873989	0.003697	31.91333	24.32084
8	0.772354	0.890452	0.003116	32.21416	25.0636
10	0.811047	0.931331	0.001917	33.02215	27.17276
12	0.864343	0.960978	0.001106	33.8648	29.56174
14	0.883145	0.967343	0.00095	34.08536	30.22097
16	0.864458	0.950929	0.001373	33.54118	28.62035
18	0.823772	0.923035	0.002236	32.77271	26.50337
20	0.808498	0.910674	0.002583	32.5337	25.87742
22	0.755111	0.875022	0.003512	32.00474	24.54417
24	0.756084	0.859996	0.00361	31.95569	24.42407
26	0.776345	0.841439	0.003843	31.84397	24.15273

V. QUALITY MEASUREMENT:

1- The MSE(**M**ean **S**equare **E**rror)of the image is defined as:

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - J(i,j)]^2$$

2- The PSNR(**P**eak **S**ignal to **N**oise **R**atio)of the image is also defined as:

$$PSNR = 10 * \log_{10}(\frac{MAX_I^2}{MSE})$$

Where MAX_I :is the maximum possible value of the image and for B=8-bit image the maximum possible value is :$2^B - 1$,which is equal 255

3- The SSIM(**S**tructure **S**imilarity Measurement) of the image is calculated on various windows of x,y size N*N image defined as:

$$SSIM(x,y) = \frac{(2\mu_x\mu_y+c_1)(2\sigma_{xy}+c_2)}{(\mu_x^2+\mu_y^2+c_1)(\sigma_x^2+\sigma_y^2+c_2)}$$

Where

μ_x : the average of x,μ_y: the average of y , σ_x^2:the variance of x , σ_y^2 the variance of y

$$\sigma_x^2 = \mathrm{E}\left[(x - \mathrm{E}(x))^2\right] = \mathrm{E}(X^2) - \mathrm{E}^2(X) ,$$

σ_{xy} the covariance between x and y ,

$$c_1 = (k_1L)^2, c_2 = (k_2L)^2$$

L :is the dynamic range of the pixel values,

k_1=0.01,k_2=0.03

4- The CORR.(**Corr**elation between images)is defined in the following :

$$CORR(x,y) = \frac{cov(x,y)}{\sigma_x\sigma_y} = \frac{E((x-\mu_x)(y-\mu_y))}{\sigma_x\sigma_y}$$

VI. Conclusions:

The above defects (noise, blur, aliasing, crosstalk) effect the super resolution of the image, the enlargement to the desired will distort the reconstructed image ,the reconstruction of MRI output with different calibration ,will generate these effects on the medical image, and any enlargement will decrease the super resolution values .The noise density with more than 0.5 will remove it using adaptive median filter, and the aliasing of the image and crosstalk which removed using filtering and reconstruction additional slices.

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