Bio-Image Resolution Enhancement Using Various Filters

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The process of medical images using Magnetic resonance imaging (MRI) is important in medical areas; such as the anatomy of human soft tissue, and diagnosis of stroke or cancer. Using mathematical and computational transformations, frequency is transferred to receive MRI images. From the process of an MRI, a large amount of frequency data are obtained. However, to determine the final image, the entire frequency information is not needed. To decrease the size of the frequency domain in a relatively large k-space, and to produce an MRI image of a brain, data was gathered in certain ways by utilizing various filters. Through utilizing MRI filters based on proposed Gaussian filters such as $y = exp(-((m-L/2)^2)/c^k)$, where m, L, c and k are all variables, and by adjusting the two main variables, c and k; relatively clear images with smaller k-space are able to be created. The constants c and k are tested from 10 and 1, increasing by 5 and 1, respectively.

Unlike a symmetric impulse filter, asymmetric filters such as $LPF(N/2-N/p:N/2+N/q)=1$ are used to show the difference in results. The constants p and q are tested from 10 and 5, increasing by 5 each. When the exponent k in the proposed filter equation is in between 2 and 3, the best efficiency occurred, but a new algorithm is needed to find the exact number since the number is not just an integer. This research of combining the observed data and the proposed equation has been conducted to observe an improved algorithm that not only increases the quality of an MRI image, but also decreases the time it takes to produce the image.

Histogram equalization and histogram smoothing techniques was employed to enhance the MRI image of a brain with Alzheimer's disease, to determine specific information and evaluate diseases.
Histograms of a brain affected with Alzheimer's disease are different from histograms of a normal brain, because they show uneven distribution with peaks at random points. Six MRI scans were obtained from three different patients with varying degrees of severity of Alzheimer's disease, in order to compare the respective histograms of the three patients. The first individual's MRI scans shows a normal, healthy brain with an MTA score of zero. There is no atrophy visible in the hippocampal or global regions. The histogram of an MRI scan of a normal brain shows moderate distribution with low peaks at around contrast #110 and #180, and the MRI scan is clear and equalized due to the evenly distributed frequencies. The second individual's MRI scans shows different conditions or stages. The histogram of the brain with severe stage shows an uneven distribution with peaks at around contrast #10 and #40.

The third individual's MRI scans shows different stages and was analyzed. In this case, the histogram is distributed towards the white end, which is the result of the atrophy due to the severe stage. Through the histograms obtained from the MatLab, the severity of the disease can be assessed, and specific levels of severities may have specific patterns to their respective histograms. However, to determine the level of severity of Alzheimer's disease, more information through further analysis needs to be carried out.

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Introduction

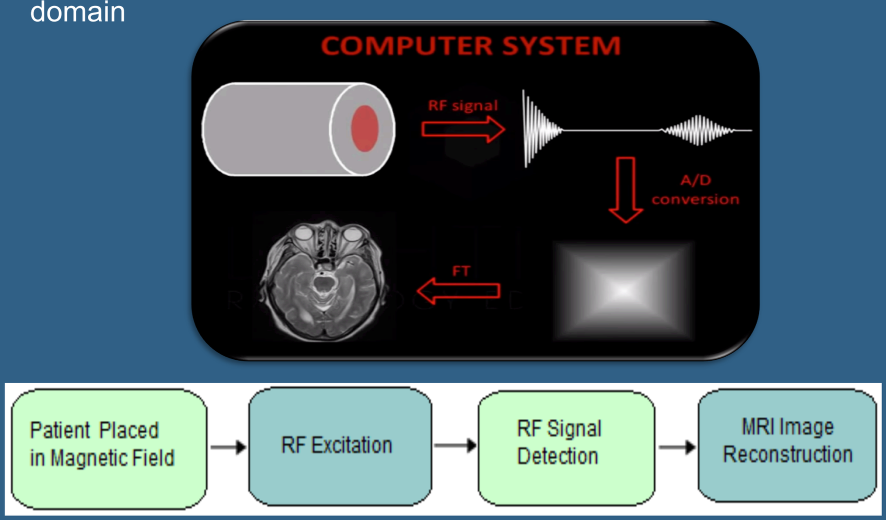
The main purpose of this research is to develop better algorithm that would enhance the quality of the final MRI image, decrease the amount of time taken to produce it, and produce the image with less ringing artifact.
To generate the MRI images, K-space(frequency domain) has to be transferred to image domain using numerical transformations[1].
Ample amount of the frequency data can be obtained from MRI process, but not all the frequency information are required to create the final image [2].

In this research, we manipulated the rectangular filters, Gaussian functions, and new functions were tried to observe the various clarities of the final images.
Often, the process of transformation from frequency domain to image domain requires time because Inverse Fourier Transformation takes every frequency points to determine the final output image. However, if a proper function is multiplied to K-space, it results in reduced domains of frequency, which will be used to determine output images

The purpose of the present research is to develop a more efficient low pass filter or filter function, in order to increase the resolution of the image, decrease the Ringing Artifact [3], and decrease the time required to produce the image.

Research Steps

The process of the transformation from frequency data to image domain



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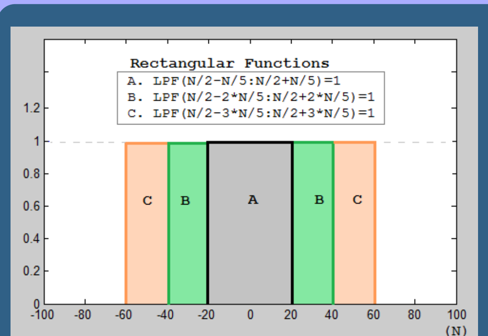
Part. A. Filter Design



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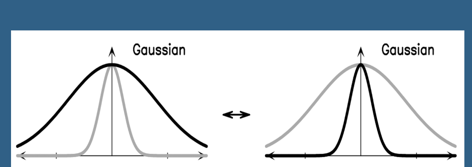
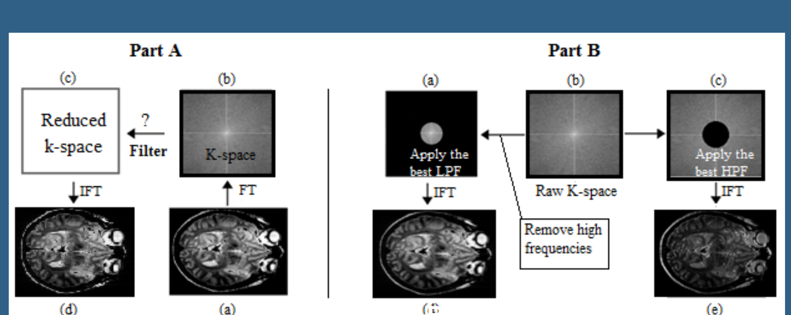


However, if a proper function is multiplied to K-space,
it results in reduced domains of frequency, which will be used to determine output images.

Part B. Applications

Selectivity and transformation of k-space to image domain

(b) to (a) : High frequencies removed
(b) to (c) : low frequencies removed

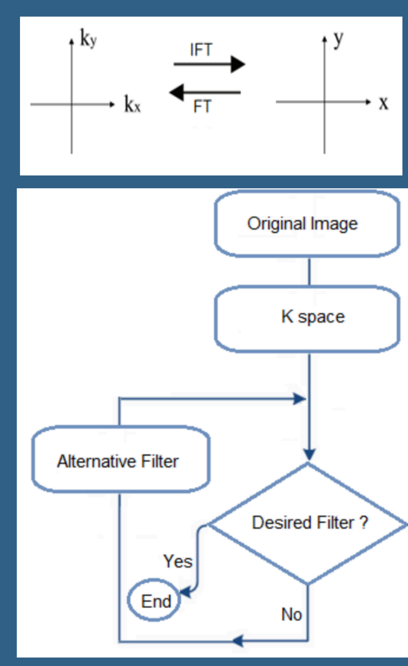


Part A.
Find an efficient filter to Produce better MRI image

Test the filters obtained from Part A
(b) to (a) : High frequencies removed
(b) to (c) : low frequencies removed

Methods

Solution Process



Fourier Transformation

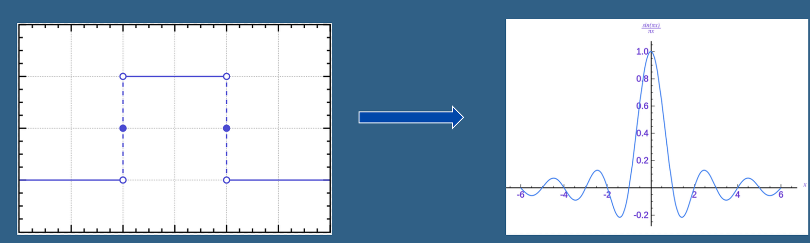
- The Fourier transform is the frequency domain representation of the original signal in the image domain

$$S(\omega)=\int_{-\infty}^{\infty} s(t)e^{-j2\pi f t}dt \qquad s(t)=\int_{-\infty}^{\infty} S(f)\,e^{j2\pi f t}df$$

$$\longrightarrow$$

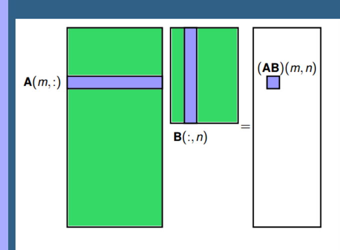
$$S(\omega)=\int_{-\infty}^{\infty} f(t)e^{-j\omega t}dt \qquad s(t)=\frac{1}{2\pi}\int_{-\infty}^{\infty} S(\omega)\,e^{j\omega t}d\omega$$

- The Fourier transform decomposes a function of time (or **image** signal) into the frequencies that make it up.
- The Fourier transform of a function of time(image) itself is a complex-valued function of frequency, whose absolute value represents the amount of that frequency present in the original function
(Absolute value of the complex number=Magnitude of the frequency).



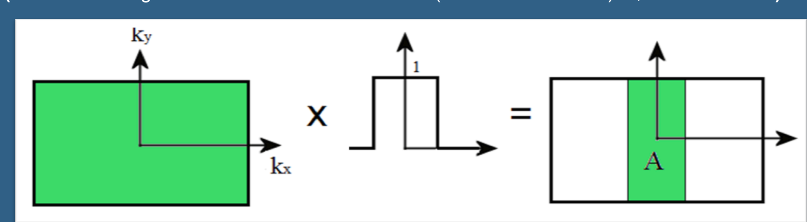
Data

Part. A. Filter Design

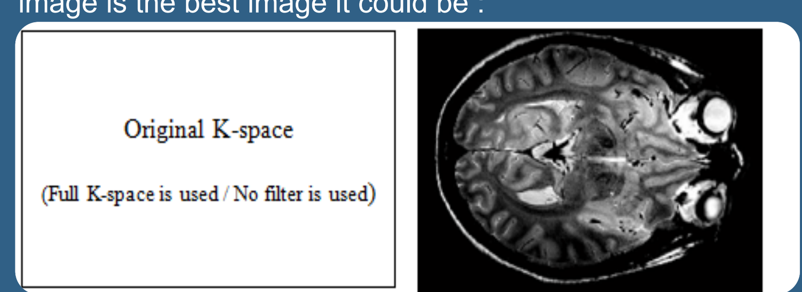


K-space is a matrix, which is composed of M rows and N columns, where kx is interpreted in real time to give N samples and ky is adjusted to M samples. This conversion of axes allows K-space in (m,n) matrix to be converted into kx-ky plane, which can be used to create an image in an x-y plane. Therefore, it is valid to say that an MRI image is the magnitude of the Fourier transform of the K-space image.

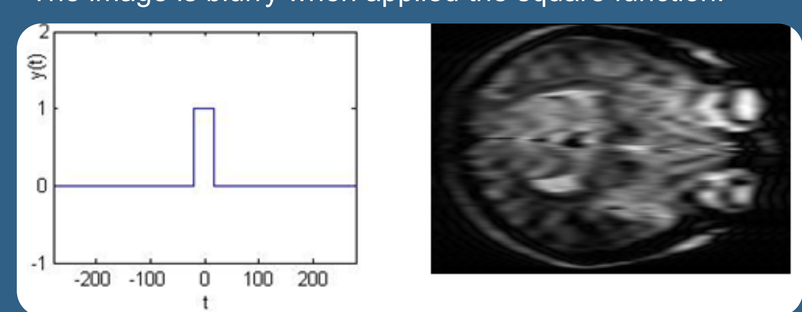
Multiplication of K-space and square function causes reduction in K-space
(Tested Rectangular function in the MATLAB LPF(N/2-N/10:N/2+N/10)=1, AC=BC= N/10)



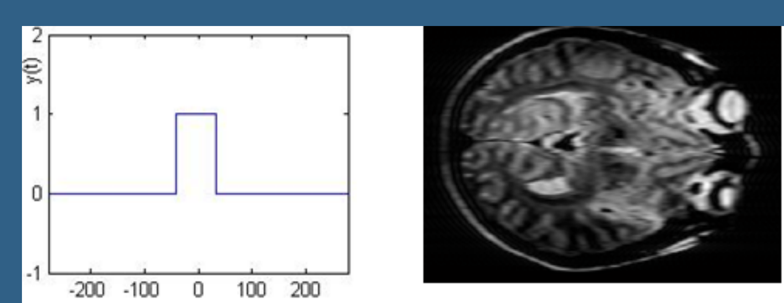
In the original image that uses the full K-Space, the MRI image is the best image it could be :

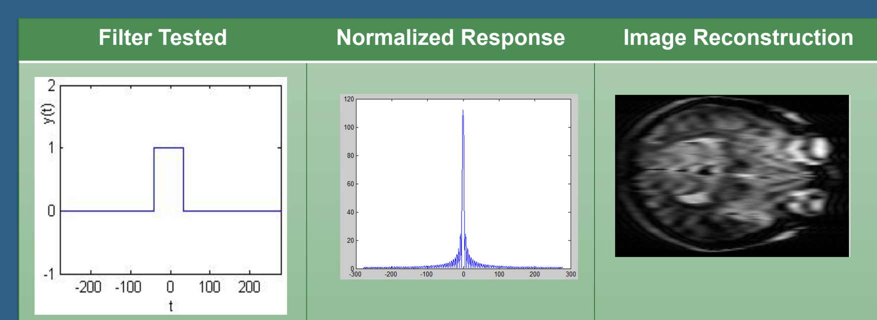


The image is blurry when applied the square function:



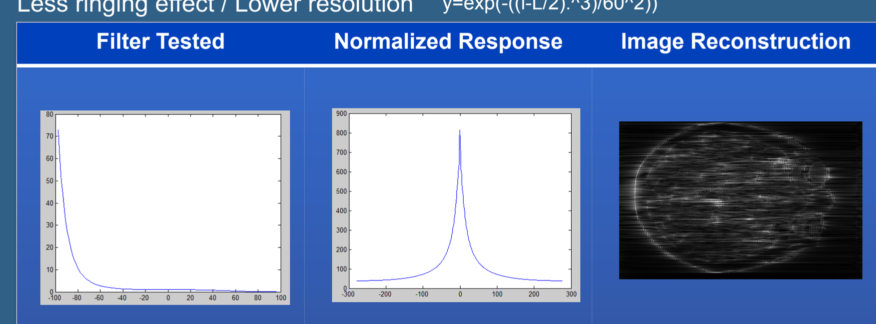
The image quality is slightly improved when given a larger domain:





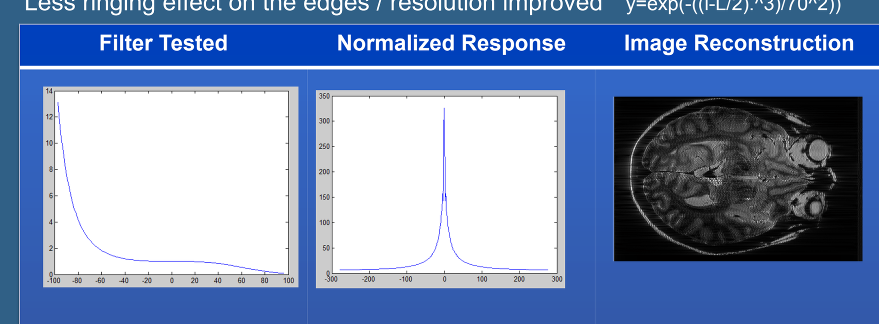
Too much ringing effect on the edges / Low resolution / narrow LPF contains less information on K-space, Square function {x|-13<x<13} / Wavy Sinc function

Less ringing effect / Lower resolution y=exp(-((l-L/2).^3)/60^2))

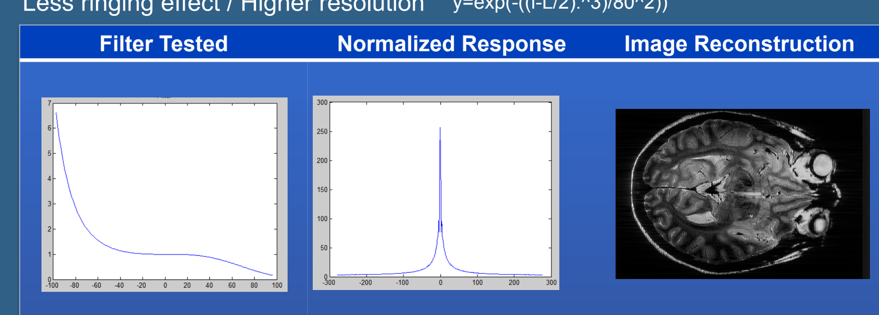


Less ringing effect on the edges / but resolution got worse

Less ringing effect on the edges / resolution improved y=exp(-((l-L/2).^3)/70^2))

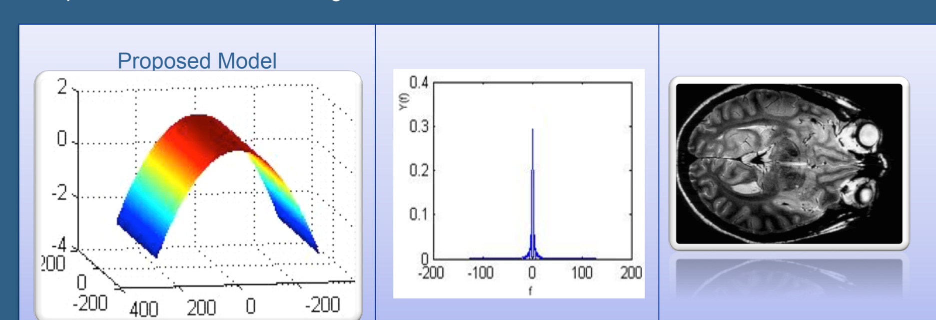


Less ringing effect / Higher resolution y=exp(-((l-L/2).^3)/80^2))



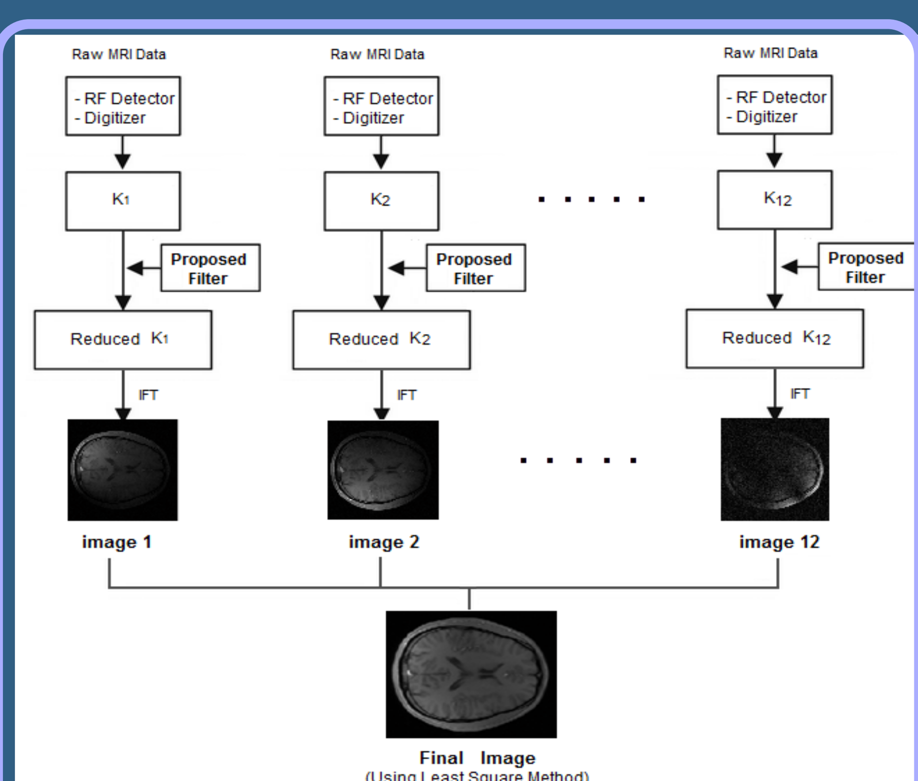
Better resolution because the wide Gaussian function contains both high and low frequency regions from K-space

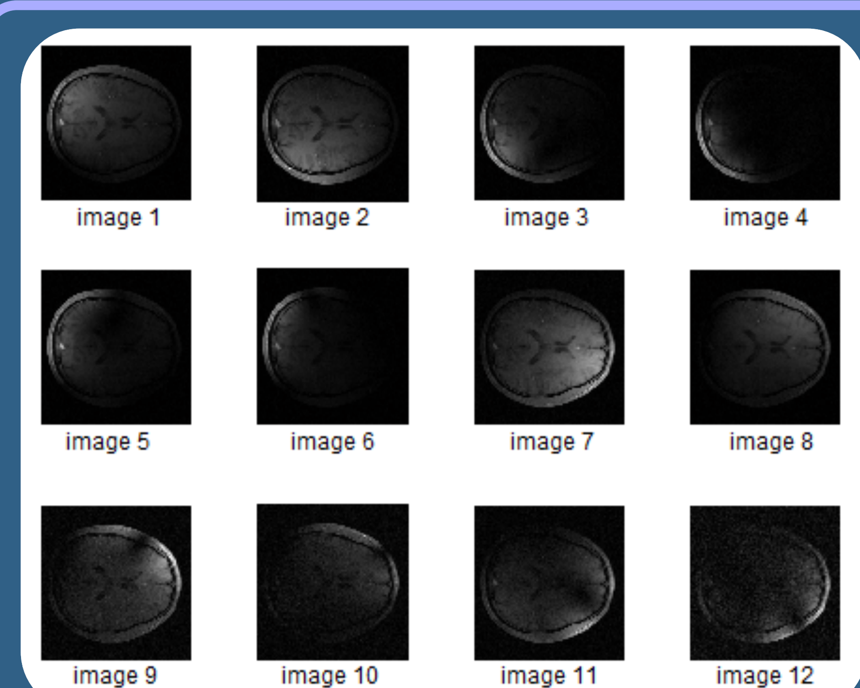
Proposed Model 2: Clearer edges



Filter is similar to the wide Gaussian / Produce clearer image

Final image from 12 K-space(using the proposed filter. Total frequency matrix size : 557x365x12)



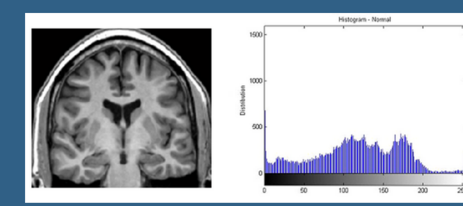


Twelve different images from 12 coils of an MRI

Histogram Analysis

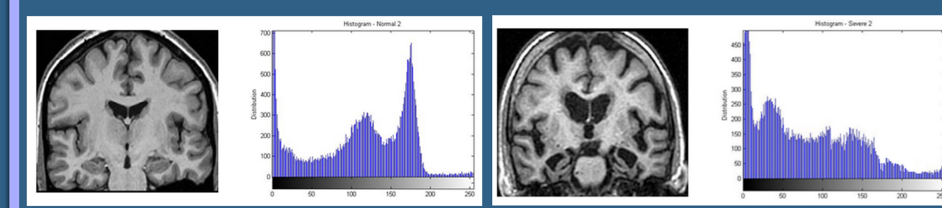
Different from the histogram of the MRI of the normal brain, the histogram of the brain with severe stage shows a rather uneven distribution with peaks at around contrast#10 and #40. Finally, the third individual's three MRI scans with different stages were analyzed. In this case, the histogram is distributed towards the white end, which is the result of the atrophy due to the severe stage. With the histograms obtained through the MatLab, the severity of the disease can be assessed, and specific levels of severities may have specific patterns to their respective histograms.

Patient A (Normal)



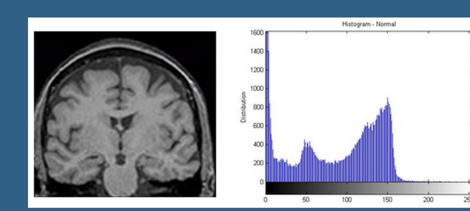
Equalized - The image is clear, because the pixels are evenly distributed.

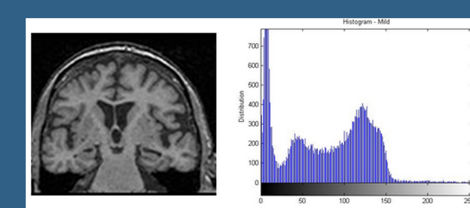
Patient B (Normal/Severe)

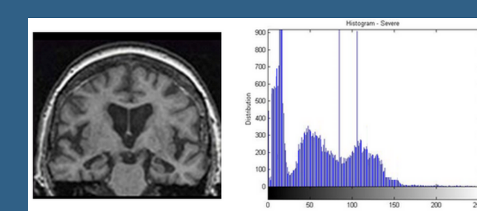


Patient C (Normal/Mild/Severe)

We can see that the histogram is very heavily distributed towards the black end. That is the result of the amount of atrophy the severe stage embodies (darker, blacker color → more empty space)







Conclusions and Future Work

Many filters are good on reducing the size of K-space, but most of those filters had the unwanted effect, called ringing effect(sharp "edges" of the images are blurred). In this research, new experiments were carried out with several modified filters to reduce the ringing effect and improve the resolution of an MRI image to a degree, and finally proposed an efficient function as a new filter.

1. The proposed filter is different from the rectangular function, Gaussian function, and circle function, but trial and error were done on the new filter to have all the advantages or properties of the 3 functions.

2. The best efficiency occurred when the exponent n in the proposed filter equation is in between 2 and 10, but a new algorithm is needed to find the exact number since the number is not just integer.

3. Collected vast raw data from a patient were tested to create 12 sub images using the proposed filter, and the final image was constructed successfully using the coordinate transformations and least square method. But because other methods are also possible to visualize the image, it is desirable to compare the methods each other.

4. Working with large matrixes would be very time consuming for home computers, and even the most recent PC cannot open relatively large MATLAB file, the 12 Mega Byte memory K-space data(*.mat).

5. We have obtained the MRI scans of patients with varying degrees of severity of Alzheimer`s disease after developing image-processing algorithms, and have also analyzed the histograms of the scans in search for a common pattern between the common severities

References

[1] Stark DD, Bradley WG. Magnetic Resonance Imaging. 3rd edition. C V Mosby, 1999.
[2] Mezrich R. A perspective on K-space. Radiology 1995; 195(2):297-315.
[3] Zhuo J, Gullapalli RP. AAPM/RSNA physics tutorial for residents: MR artifacts, safety, andquality control. Radiographics 2006; 26(1):275-97.