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Biomedical Image Acquisition

Lab 4 – MRI

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1 Introduction

Magnetic Resonance Imaging (MRI) is based on the phenomenon of nuclear magnetic resonance. A system of nucleuses that have angular momentum or spin are magnetized by an external magnetic field producing a magnetization vector with a frequency known as the Larmor frequency. This magnetization vector has two components, the transverse magnetization and the longitudinal magnetization. The signal we observe in an MRI is a radio frequency (RF) pulse produced by the spinning transverse magnetization. [4]

In the first part of this lab we will be processing an MRI data of a mouse brain. Our goal is to reconstruct the magnetic resonance images from the data. We will reconstruct the MR Image of the mouse brain in Fourier space data in axial slice view, reconstructing it in K-space and image space. We will also reconstruct an image in the sagittal plane. Then we will investigate the effects on the reconstructed images from a high and a low pass filter in Fourier space.

For the second part of the lab we will be investigating the MRI 3D visualizations from three human brain subjects. The dataset will be extracted from Open Access Series of Imaging Studies (OASIS) and will be visualized by a 3D visualization software called FIJI. The MR Images of the three brains will be presented in volumetric, sagittal slice, coronal slice, and axial slice view. We will then locate the hippocampus of one of the brains, analyze the visualized MR Images, and comment on their morphological differences.

2 Methods

2.1 Processing MRI Data of Mouse Brain

We begin by importing in the MRI data of the mouse brain. We choose the z-axial slice 125 to image in Fourier space. Given that the image field of view (FOV) is 1.92 cm by 1.28 cm by 1.28 cm (z by x by y), we can calculate the number of cycles for the x and y axis ranges (Δu and Δv) with equation (1) and equation (2) respectively,

$$\Delta u = 1/FOV_x \tag{1}$$

$$\Delta v = 1/\, FOV_y \tag{2}$$

where $FOV_x = FOV_y = 1.28$ cm. The full length of the data is 128 samples, but when looking for the maximum and minimum we only consider half to centralize the coordinate system at the 64th sample. To find the maximum and minimum cycles per centimeter of Δu and Δv, they should be the same since the image is a square, we use the equation (3) and equation (4) respectively

$$v_{max} = u_{max} = 64\times\Delta v \tag{3}$$

$$v_{min} = u_{min} = -64\times\Delta v \tag{4}$$

We can then determine the range for x-axis and the y-axis. The result of these calculations can be seen in Section 3.1.

We chose to image 125th z-axial slice data of the mouse brain. To image in Fourier space, the slice is squeezed into two dimensions by using the function ‘squeeze’ in MATLAB, the absolute value of the data is computed to obtain the magnitude and finally we log of each section to have a more dynamic range for visualization. The resulting image can be seen in Section 3.1.

To reconstruct the 125th z-axial slice of the mouse brain in image space, we take the absolute value and use the command ‘ifft2’ to inverse Fourier transform the data.

The sagittal slice of the brain was found by obtaining the data along the y-z plane for a specific x-axial slice. We chose the 58^{th} x-axial slice. This data was squeezed into two dimensions, inversed Fourier transformed and finally we took its absolute value. The resulting image can be seen in Section 3.1.

Next, we observe the effects of low and high pass filters with various cutoff values. The low pass filters are obtained by symmetrically zeroing the low frequency components of the data on both the top, bottom, and sides in Fourier space at various cutoff values. This creates a border of zero valued data around the image in Fourier space and can be seen in Section 3.1.

Similarly, the high pass filter was obtained by zeroing the high frequency component of the data in Fourier space. This time the filtered data of value zero is creates a square and the border is the high frequency data. An example of the data when filtered by a high pass plotted in Fourier space can be seen in Figure 5 in Section 3.1. We repeated this procedure but at different cycles per cm values to vary the cutoff values. To observe the reconstructed image, we took the absolute value and inverse transform of the data.

To calculate the cutoff value for the low pass filter in Fourier space by using equation (5).

$$Cut\ off\ value = (64 - i) * (1/1.28) \tag{5}$$

where i determine the size of data we are zeroing and ranges between 1 to 64. The higher the i value the more high frequency component data we remove and thus the smaller the cut off value.

To calculate the cutoff value for the high pass filter in Fourier space, equation (5) is used again but this time i determine the size of data we are keeping and ranges between 1 to 64. The higher the i value the more high frequency component data are kept and thus the higher the cut off value.

2.2 Extracting 3D Visualization of Brain from MRI Data

We used the 3D visualization software FIJI to look at the dataset from OASIS. The dataset extracted was from three subjects that did a to assess their mental cognition. The test is called the Mini-Mental State Examination (MMSE). The first subject is a 52-year-old who scored a 30 in the MMSE which is a perfect score. The second subject is an 81-year-old who also a scored 30 in the MMSE. Lastly, the third subject is an 80-year-old who only scored a 23 in the MMSE. These subjects are essentially a dataset from a young and cognitively normal brain, an elderly and cognitively normal brain, and an age-matched cognitively-impaired brain.

The header files and image data files dataset for the three subjects that were extracted from OASIS were then dragged and dropped onto FIJI. After the dataset was loaded into FIJI, we used the FIJI plugin 'Volumetric View,' set the mode to 'Slice,' and adjusted the image position to get the sagittal, coronal, and axial slices. We then changed the mode to 'Volume' to get the volumetric view of the brains of the subjects. The resulting images captured are found in Section 3.2.

We also identify the hippocampus in the brain of the 52-year-old subject. The brain with the hippocampus identified is shown in Section 3.3.

3 Results

3.1 MRI Data of Mouse Brain

Given that the $FOV_x = FOV_y = 1.28$ cm, using equation (1) and equation (2), we get that x and y axis ranges ((Δu and Δv) are given in equation (6).

$$\Delta u = \Delta v = 0.78125\ cm \tag{6}$$

Then from equation (3) and equation (4), the maximum and minimum ranges of Δu and Δv are seen in equation (7) and equation (8).

$$u_{max} = v_{max} = 50\ cycles/cm \tag{7}$$

$$u_{min} = v_{min} = -50\ cycles/cm \tag{8}$$

The K-space image and the reconstructed image in image space for the MRI data of the 125th z-axial coronal slice of mouse brain can be seen in Figure 1 and Figure 2.

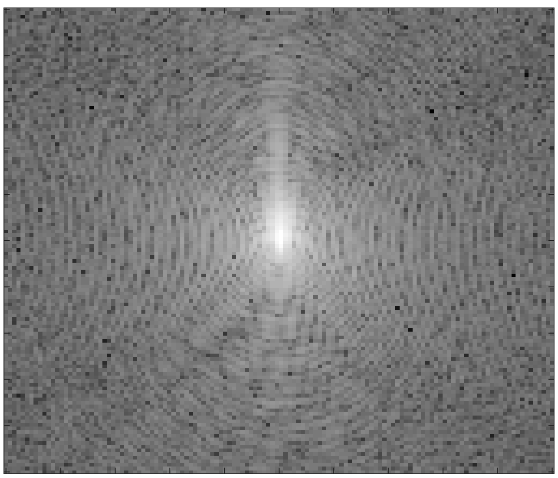

Figure 1: K-Space for MRI Signal of Mouse Brain

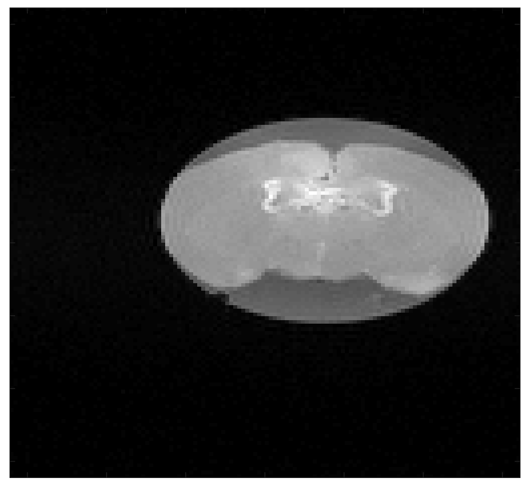

Figure 2: Reconstructed image of coronal slice of the mouse brain in image space

Figure 3 shows a sagittal slice of the mouse brain in the test tube in image space. This is the 58th x-axial slice of the data.

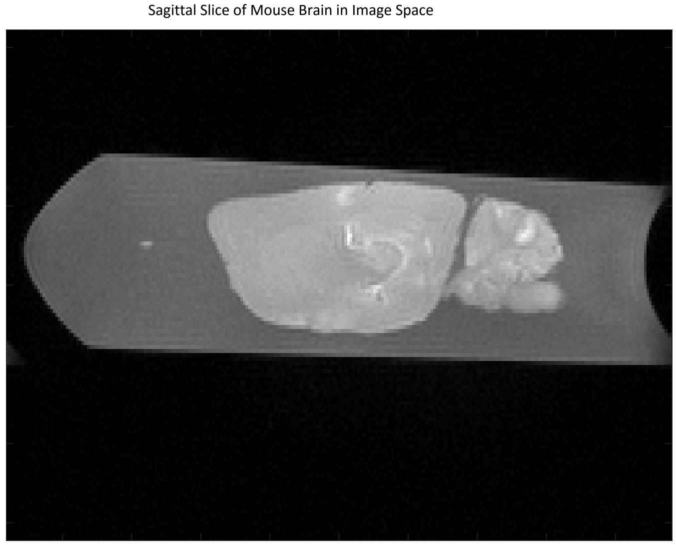

Figure 3: Reconstructed image of sagittal slice of mouse brain

The MRI data in Fourier space after applying a low pass and high pass filter at cut off values of 38.2813 cycles/cm and 15.625 cycles/cm are seen in Figure 4 and Figure 5 respectively.

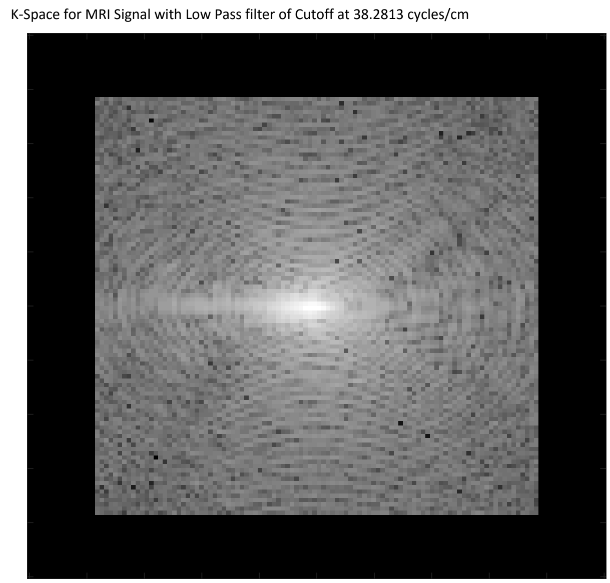

Figure 4: MRI Data in Fourier Space after applying a low pass filter with cutoff at 38.2813 cycles/cm

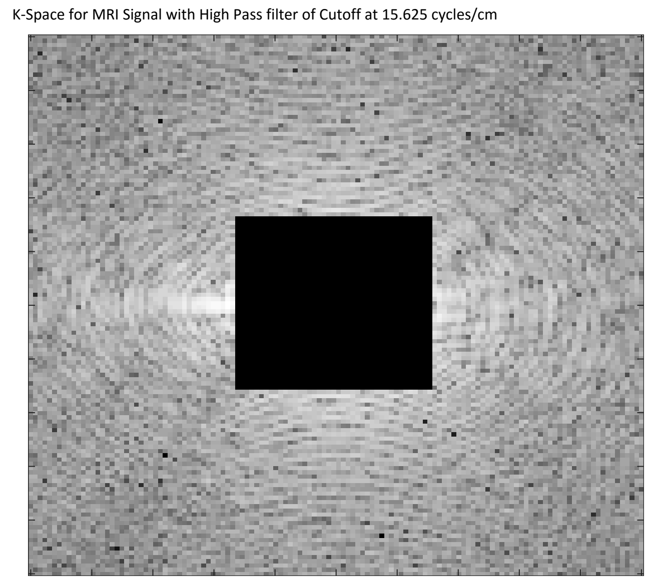

Figure 5: MRI Data in Fourier Space after applying a low pass filter with cutoff at 15.625 cycles/cm

The 125th z-axial coronal slice of the mouse brain in image space with a low pass filter for cut off values 38.2813 cycles/cm, 10.9375 cycles/cm, and 3.125 cycles/cm can be seen in Figure 6, Figure 8, and Figure 10 respectively. The same slice with a high pass filter added for cut off values of 15.625 cycles/cm, 4.6875 cycles/cm and 1.5625 cycles/cm are seen in Figure 7, Figure 9 and Figure 11.

Figure 6: The reconstructed image with a low pass filter with cutoff at 38.2813 cycles/cm

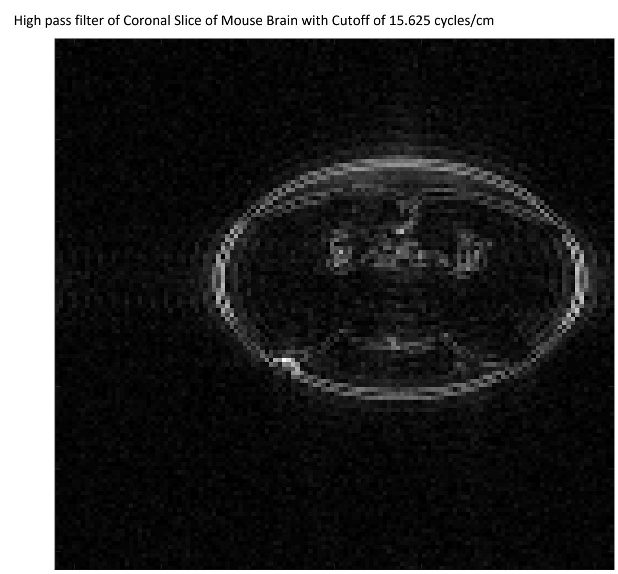

Figure 7: The reconstructed image with a high pass filter with cutoff at 15.625 cycles/cm

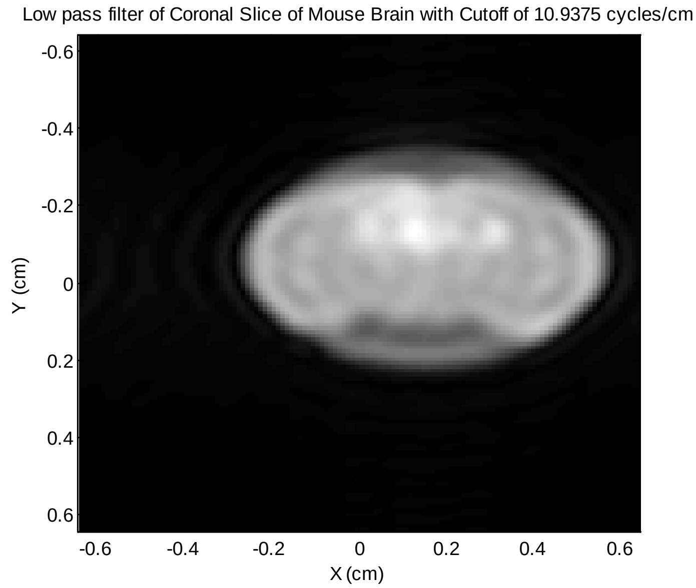

Figure 8: The reconstructed image with a low pass filter with cutoff of 10.9375 cycles/cm

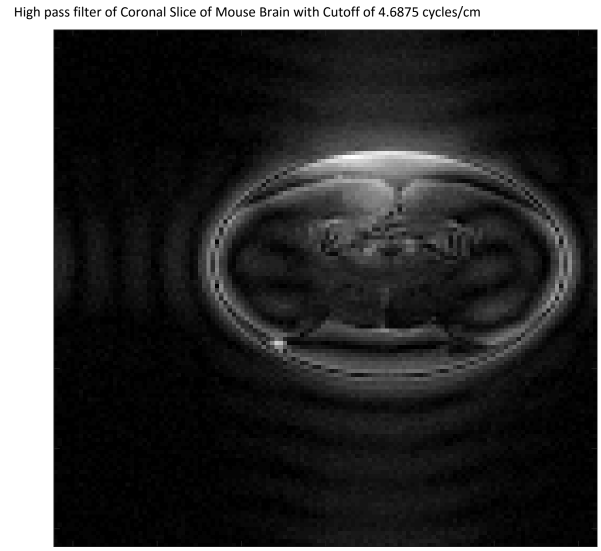

Figure 9: The reconstructed image with a high pass filter with cutoff at 4.6875 cycles/cm

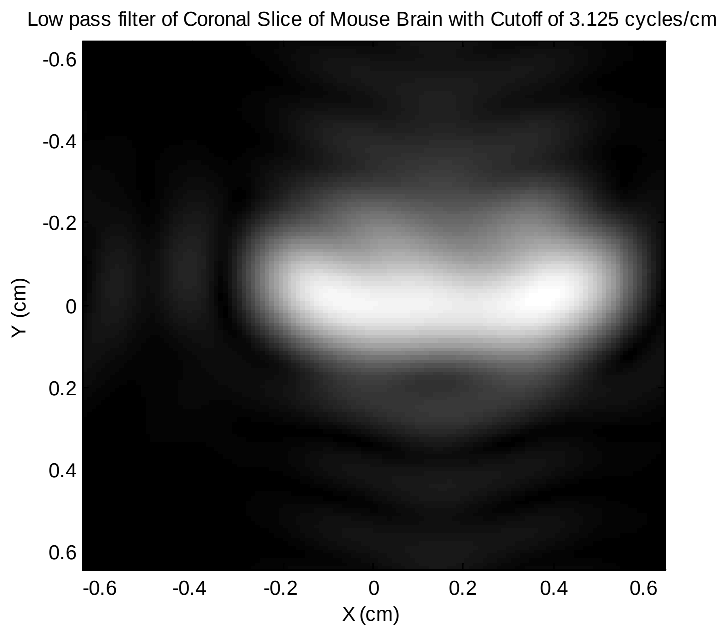

Figure 10: The reconstructed image with a low pass filter with cutoff at 3.125 cycles/cm

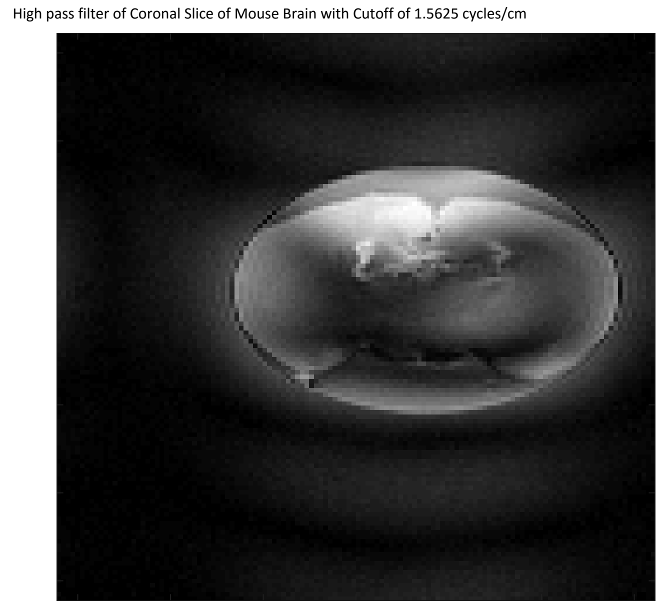

Figure 11: The reconstructed image with a high pass filter with cutoff at 1.5625 cycles/cm

3.2 3D Visualization of the Human Brain

The slices and volumetric view of the brains of the three subjects are shown below. Table 1 identifies each type of slice used for reference.

Table 1: Representation of Various Slice Views

Sagittal Slice	The sagittal slice separates the left and right sides (lateral view).
Coronal Slice	The coronal slice separates the front from the back (frontal view).
Axial Slice	The axial slice separates the bottom from the top (top view).

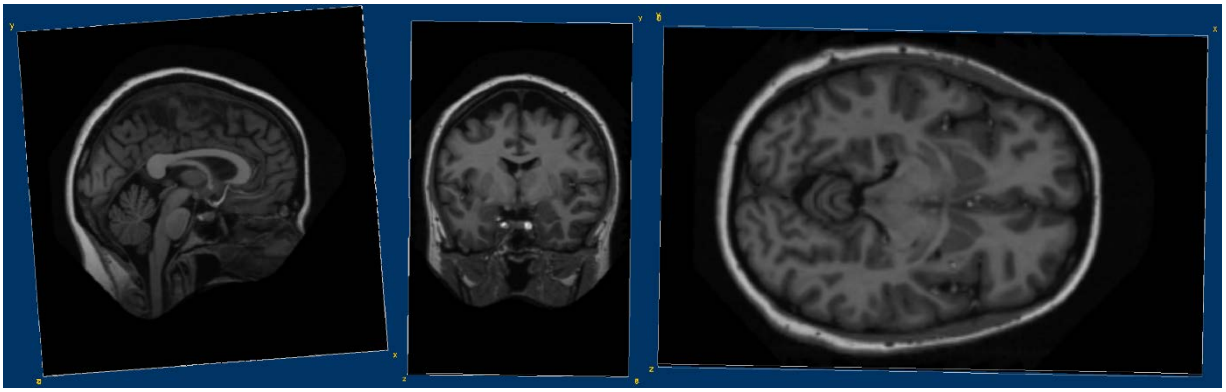

Figure 12: From left to right, the sagittal slice, coronal slice, and axial slice of a brain of a 52-year-old who scored a 30 in the MMSE

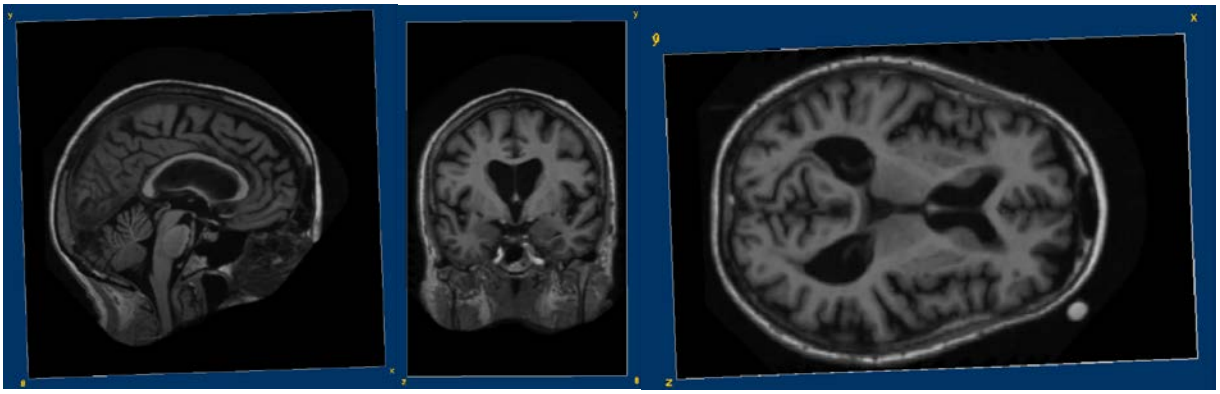

Figure 13: From left to right, the sagittal slice, coronal slice, and axial slice of a brain of an 81-year-old who scored a 30 in the MMSE

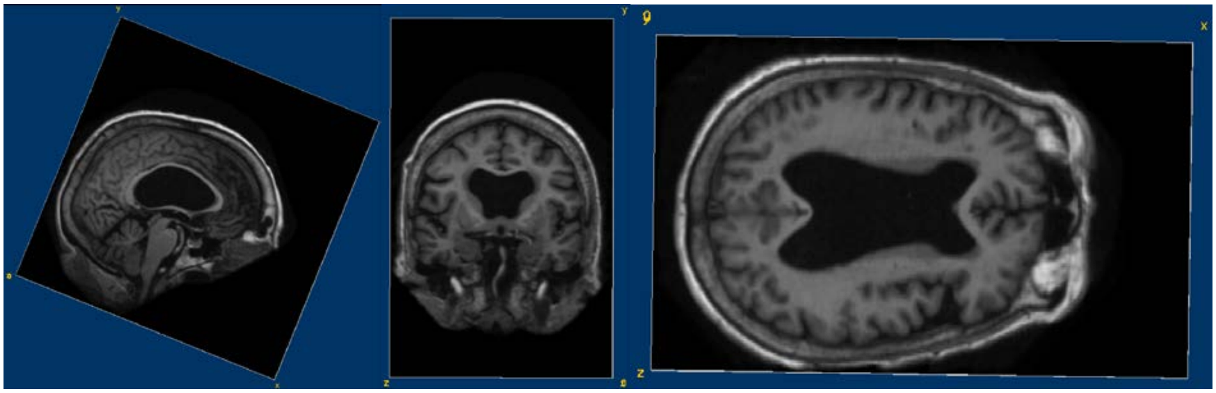

Figure 14: From left to right, the sagittal slice, coronal slice, and axial slice of a brain of an 80-year-old who scored a 23 in the MMSE

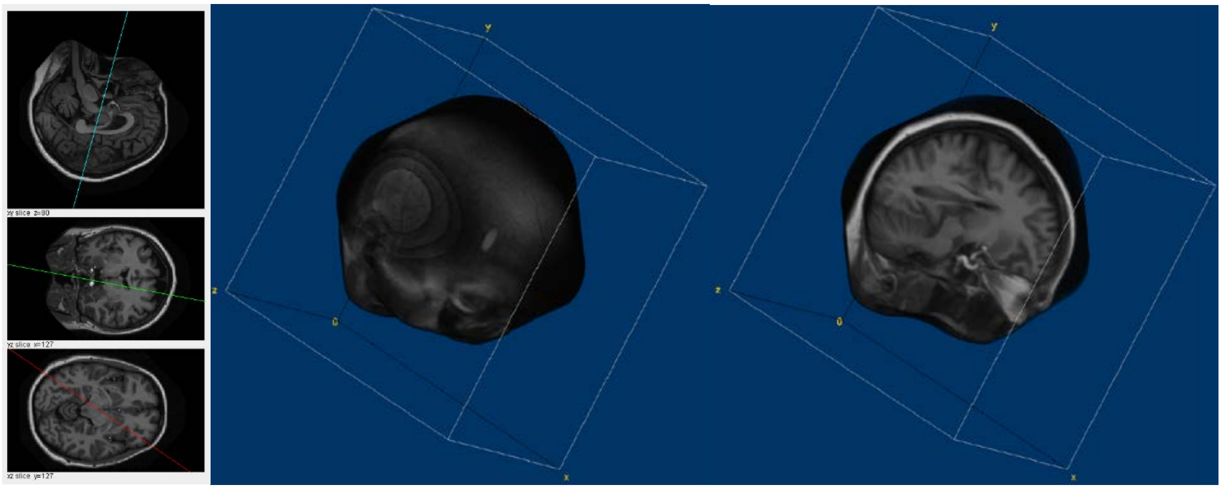

Figure 15: Volumetric view of a brain of a 52-year-old who scored a 30 in the MMSE

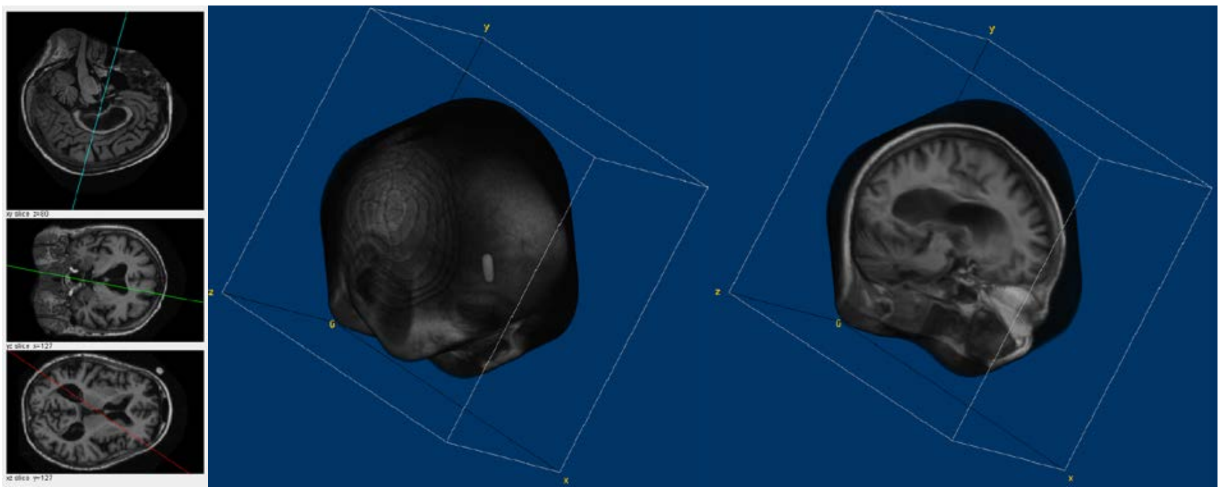

Figure 16: Volumetric view of a brain of an 81-year-old who scored a 30 in the MMSE

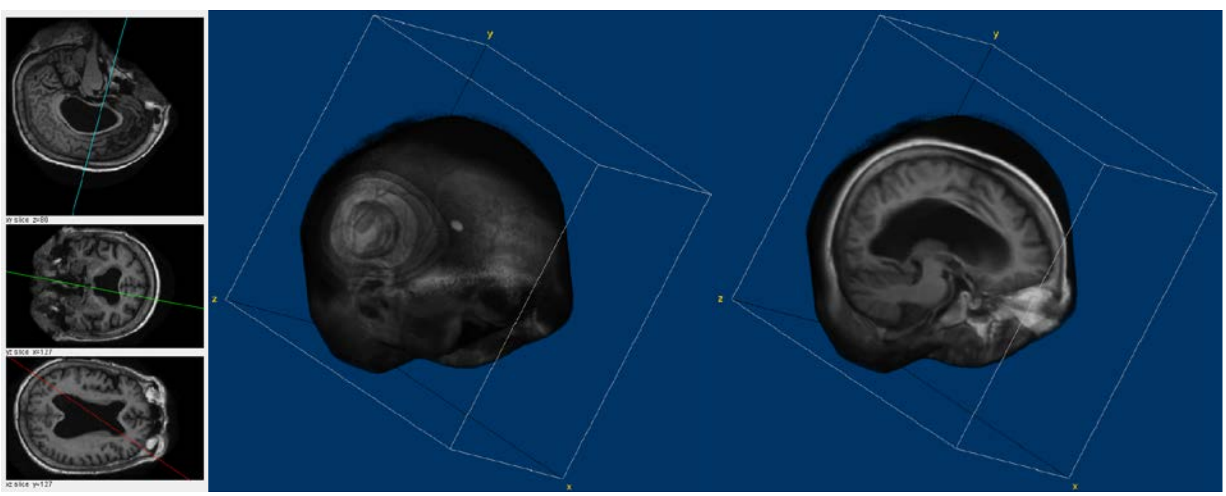

Figure 17: Volumetric view of a brain of an 80-year-old who scored a 23 in the MMSE

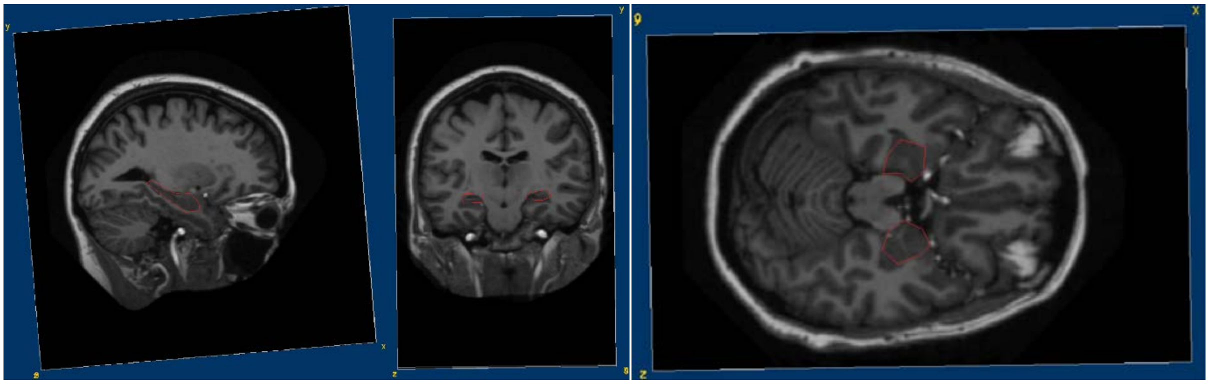

Figure 18: Located from left to right are the hippocampus locations in the brain of the 52-year-old subject in the sagittal slice, coronal slice, and axial slice which are indicated by the red outline

3.3 3D Visualization Analysis

Figure 18 above shows the location of the hippocampus inside the brain of the 52-year-old in each of the slices. The hippocampus is an important organ of the brain as it is mostly associated with long-term memory and spatial navigation [2].

We should note here that in MRI imaging, the dark spots mean there is nothing being scanned.

Looking at Figure 12, Figure 13, and Figure 14 we can see a lot of morphological differences between the brains. The 52-year-old brain in Figure 12 has more cerebral fluid or inner parts compared to the 81-year-old brain in Figure 13. We can see that the inner parts of the brain have shrunk, leaving a dark hole. We can even see that the cerebral cortex or outer parts have also shrunk and become darker, but these are not as pronounced as the shrinking of the cerebral fluids in the middle.

4 Discussion

4.1 MRI Data of Mouse Brain

We used the Allen Brain Atlas to look up the sagittal slice we reconstructed in Figure 3. The reconstructed image we obtained of the 58th x-axial slice is very similar in shape to the image from the atlas, Figure 16. Thus we can say that the 58th x-axial slice of the MRI data we obtained is position 98 of the mouse brain in the atlas. The atlas also states that this slice is sagittal level 8 [1].

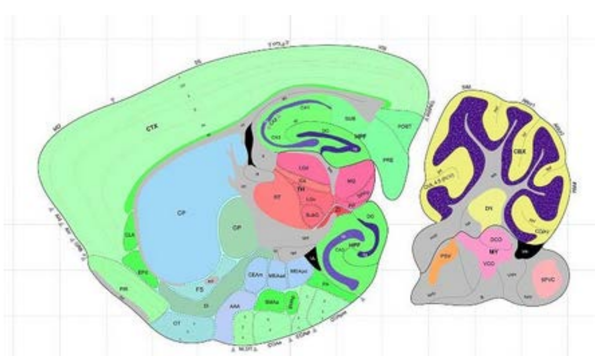

Figure 19: Position 98 of the Sagittal slice of the Mouse Brain [1]

We expect a lot of blurriness when the cutoff is a low value since we will only have very low frequency components, which is where all the blurring occurs. If we increase our cutoff value, we let through some higher range of frequency in Fourier space and thus the reconstructed image will be less blurry in image space. This expected result matches with the images we obtained Figure 6, Figure 8 and Figure 10 since as we go lower in the cutoff value our images get blurrier.

Adding the high pass filter with a large cutoff value means we keep only very high frequency components and consequently, the edges of the image will be sharper. The image will also have mostly dark intensity components and thus will be more uniform in intensity at large cutoff value. If we decrease the cutoff value, we let through some lower range of frequency components thus our image will be more dynamic and have some bright intensity components and be less uniform. The edges of the image will also be less sharp.

We can see from our images in Figure 7, Figure 9 and Figure 11 that this expected result holds true. At a small cutoff value of 1.5625 cycles/cm as seen Figure 11, we see some light components and the edges of the image is not as clearly outlined. As the cutoff value increases to 4.675 cycles/cm Figure 9, we can see that the image has more dark parts and the shape of the brain is more distinct. Increasing it even more to a cutoff of 15.625 cycles/cm, we lose most of the light intensity components, the image becomes more uniform in intensity and edges of image are not as clear as seen in Figure 7.

4.2 3D Visualization of the Human Brain

Figure 12 and Figure 13 are slices between two cognitively-normal brains, so we know that the cerebral fluid and cortex just shrink as we age so the loss of fluids and cortex is normal. This is backed up by the fact that despite the apparent big dark whole in the brain, the 81-year-old subject still scored a 30 on the MMSE test. However, when comparing the 81-year-old brain in Figure 13 to the 80-year-old brain in Figure 14 then it is not just a simple shrinkage of the cerebral fluids. This cognitively-impaired brain shows a lot more darker spots than the age-matched cognitively-normal brain. The damaged brain does not show shrinkage from old age, it shows the cerebral fluids in the middle to be missing and the cerebral cortex of the outer brain to be less pronounced. The outer parts of the damaged brain are less detailed when compared to the normal brain.

There is a big difference between the age-matched brains. We can see why the 80-year-old brain only scored a 23 in the MMSE test. It is because there are a lot of cerebral fluids and cerebral cortex missing in his brain. They have shrunk so severely that the expected hole or dark spots found in a cognitively-normal brain is almost twice as big in this damaged brain.

Looking at the volumetric view of the three subjects, we can see that the brain retains its shape to the skull. Either from old age or from damages, the brain does not shrink outside-in like a rotten fruit, we see that it instead shrinks from the inside-out. Although there is less cerebral fluid in the 81-year-old brain and it shows a dark whole. This is normal and the subject should not worry or panic. However, when there are significantly less amounts of cerebral fluids like in the 80-year-old brain then we know that the subject has a damaged brain.

4.3 Hippocampus

We chose to use the 52-year-old brain because the shrinkage of both the normal and damaged older brain would make it harder to identify the hippocampus. The hippocampus was a bit tricky to locate using the Volume Viewer in FIJI because it is in that specific spot in the brain. Therefore, we could not just use the sagittal, coronal, or axial slices to guess where the hippocampus was located. In the Volume Viewer plugin, we had to change the distance of the slice into the brain to locate what resembled the hippocampus.

Since the hippocampus is associated with long-term memory, we related it to Alzheimer's disease. This disease is associated with memory loss, difficulties with thinking, and problem-solving or language. It causes damage in the brain that are usually found in the hippocampus [3]. So, in an MRI scan that shows a damaged hippocampus might be an early symptom of Alzheimer's disease. Looking at the location of the hippocampus in Figure 18 then comparing it with the cognitively-impaired brain in Figure 14, we can see that the hippocampus must have been damaged. The compared slices are not in the same depth but the general area where the hippocampus is located looks damaged judging by the big black hole in the cognitively-impaired brain. The hippocampus being damaged can be the reason why this subject only scored a 23 in the MMSE test.

5 Conclusion

The sagittal slice reconstructed matches with the image in the Allen Brain atlas. We identified it to be the position 98 and sagittal level 8 image in the atlas.

We added low pass filters to the image at various cutoff values. The lower the cutoff value, we noticed more blurriness because there are only very low frequency components left. By increasing the cutoff we let through some higher frequency components and thus there will be less blurriness. This expected result matches with the reconstructed images we obtained when using a low pass filter.

We added high pass filters to the image at various cutoff values. The higher the cutoff value, there more high frequency components thus the sharper the edges of the image and the less lights intensity components in the image. The image becomes more uniform since only dark intensity components are left. If we decrease the cutoff we let through some low frequency components thus we should have a more dynamic image in intensities. This expected result matches with the reconstructed images we obtained when using a high pass filter.

After visualizing the three brains in volumetric, sagittal slice, coronal slice, and axial slice view we were able to see the morphological differences between the three human brains. We saw that the 81-year-old brain had less cerebral fluids and cerebral cortex as evidenced by the black holes. However, this was normal and is just part of old age because that 81-year-old subject still scored 30 in the MMSE test. On the other hand, comparing the 81-year-old with the 80-year-old subject then the images do not appear normal anymore. Since they were age-matched, the expected size of the dark hole was actually twice the size in the 80-year-old subject. This makes us agree with the fact that this subject has a cognitively-impaired brain and we can understand why the subject only scored a 23 in the MMSE test.

The hippocampus was easily identified in the 52-year-old brain. We chose that subject to identify the hippocampus on because we expected the hippocampus might be damaged or harder to find in the older brains. Since the hippocampus is associated with long-term memory and old age is usually correlated with memory loss. Then with the older aged brains the hippocampus might be damaged, therefore harder to find in the visualization software.

6 Reference

[1] Allen Institute, “Mouse Sagittal,” 2016. [Online]. Available: http://mouse.brain-map.org/experiment/siv?id=100142144&imageId=102162571&imageType=atlas&initImage=atlas&showSubImage=y&contrast=0.5,0.5,0,255,4.

[2] A. Mandal, “Hippocampus Functions,” Jan 2016. [Online]. Available: http://www.news-medical.net/health/Hippocampus-Functions.aspx

[3] M. S. Krishnan, “What is Alzheimer’s Disease?” July 2014. [Online]. Available: https://www.alzheimers.org.uk/site/scripts/documents_info.php?documentID=100

[4] J.L. Prince, “Physics of Magnetic Resonance,” in Medical Imaging Signals and Systems, 2nd ed. NJ, Prentice Hall, 2015, ch.12, pp. 410-433.

7 Appendix

7.1 Processing MRI Data MATLAB Code

```
clc;
clear all;
close all;
load('U:\ENSC 477\Lab4\Mouse\MRIdata.mat');

coronal_slice=125;

%Calculate the range of x and y axis
%X and Y axis goes from -50 to 50 cycles/cm
axismin=-64*1/1.28;
axismax=64*1/1.28;
axis=axismin:axismax;
image=log(abs(squeeze(MRIrawdata(coronal_slice,:,:))))';
imagesc(axis, axis, image);
colormap('gray')
title('K-Space for MRI Signal');
ylabel('v (cycles/cm)');
xlabel('u (cycles/cm)');

%Inverse 2D Fourier Transform
xy_axis = (-1.28/2):.01:(1.28/2);
%Squeezes slice to 2D
image=(abs(ifft2(squeeze(MRIrawdata(coronal_slice,:,:)))))'
figure
imagesc(xy_axis,xy_axis,image);
colormap('gray')
title('Reconstruction of Mouse Brain in Image Space');
ylabel('Y (cm)');
xlabel('X (cm)');

%Sagittal Slice
for i=1:256
    image = abs(ifft2(squeeze(MRIrawdata(i,:,:))));
    sagittal_slice(i,:)=image(58,:);
end
%Set up z axis
zaxis=-1.92/2:0.01:1.92/2
figure
imagesc(zaxis,xy_axis,sagittal_slice')
colormap('gray')
title('Saggital Slice of Mouse Brain in Image Space');
ylabel('Y (cm)');
xlabel('Z (cm)');

%Low pass filter
cutoff_num=20;
k_lp = MRIrawdata;
k_lp(coronal_slice,1:cutoff_num,:) = complex(0,0);
k_lp(coronal_slice,(128-cutoff_num+1):128,:) = complex(0,0);
```

```
k_lp(coronal_slice,:,(128-cutoff_num+1):128) = complex(0,0);
k_lp(coronal_slice,:,1:cutoff_num) = complex(0,0);

figure
cutoff_lp=(64-cutoff_num)*1/1.28;
image=imagesc(axis, axis,log(abs(squeeze(k_lp(coronal_slice,:,:)))))';
colormap('gray')
title(['K-Space for MRI Signal with Low Pass filter of Cutoff at ',num2str(cutoff_lp), ' cycles/cm']);
ylabel('v (cycles/cm)');
xlabel('u (cycles/cm)');

figure
imagesc(xy_axis,xy_axis,abs(ifft2(squeeze(k_lp(coronal_slice,:,:))))')
colormap('gray')
title(['Low pass filter of Coronal Slice of Mouse Brain with Cutoff of ',num2str(cutoff_lp), ' cycles/cm']);
ylabel('Y (cm)');
xlabel('X (cm)');

%High pass filter
cutoff_num2 =20;
cutoff_hp=(cutoff_num2)*1/1.28
k_hp = MRIrawdata;
k_hp(coronal_slice,64-cutoff_num2:64+cutoff_num2,64-cutoff_num2:64+cutoff_num2) = complex(0,0);
figure
imagesc(axis, axis,log(abs(squeeze(k_hp(coronal_slice,:,:)))))';
colormap('gray')
title(['K-Space for MRI Signal with High Pass filter of Cutoff at ',num2str(cutoff_hp), ' cycles/cm']);
ylabel('v (cycles/cm)');
xlabel('u (cycles/cm)');

figure
imagesc(xy_axis,xy_axis,abs(ifft2(squeeze(k_hp(coronal_slice,:,:))))')
colormap('gray')
title(['High pass filter of Coronal Slice of Mouse Brain with Cutoff of ',num2str(cutoff_hp), ' cycles/cm']);
ylabel('Y (cm)');
xlabel('X (cm)');
```