EE 575/675
DIGITAL IMAGE PROCESSING
PROJECT 3

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Instructor: Dr. Dennis Helder | Date: 10/14/19

This project provides an opportunity to become familiar with the 2-D Fourier transform and its use for image filtering and enhancement. Two images will be used: **ngirl2.img** and **campus.img**. **ngirl2.img** is a version of the now familiar Lena test image. **Campus.img** is a 512 x 512 pixel image in headerless, raster-scan format. This satellite image is from an 11-bit per pixel sensor called IKONOS that the SDSU Image Procesing Lab characterized. Thus when you load this image, specify the precision as 'uint16.' Pixel values may range from 0 to 2047. With your project report you are required to turn in one image showing the results of each of the sections listed below unless instructed otherwise. Each image should be in a headerless, raster-format file.

1. Frequency Domain Filters

Write a MATLAB function called 'freqfilt.m' that will apply a user-specified filter to a user-specified image in the Fourier domain. The program must apply an FFT to the image, filter it appropriately, and inverse FFT the result. The following specifications must be met:

1. Assume the image will be square and that it is already loaded into Matlab as a 2D variable.
2. The user should be able to specify either LPF or HPF by typing these designators as arguments in the function call.
3. The user should be able to specify either an ideal filter or a Butterworth filter by entering either 'I' or 'B' as an argument in the function call.
4. The cutoff frequency of the ideal filter should be user-specified on a scale from 0 to ½ cycle/pixel, again as an argument in the function call.
5. The cutoff frequency and the order of the Butterworth filter should be user-specified in the function call.
6. Example: output = freqfilt(lena, LPF,B,0.25,3). Arguments must be in this order.
7. For the case of a HPF, the user should be prompted to enter in a scaling factor, α, where $0 \leq \alpha < 1$ that scales the stop band of the HPF so that at DC it would be a value of α greater than zero and all values within the stopband are also scaled by α. If $\alpha = 0$, then no scaling occurs. Additionally, when $\alpha \neq 0$ the DC value of the image should not be altered; that is, the DC value of the filter equals unity under these conditions.

Test your program for LPF with cutoff frequencies of 1/4 cycle/pixel and 1/8 cycle/pixel, and Butterworth filters of 2nd and 4th order. Use the image 'campus.img' for this part of the project. For each case show the resulting image, and briefly discuss the effect that your filter had on the image (Hint: Get Your Nose In The Data!). You should also discuss the differences between the Ideal and Butterworth filters particularly emphasizing how the experimental results in this project compare to the theoretical similarities/differences we discussed in class.

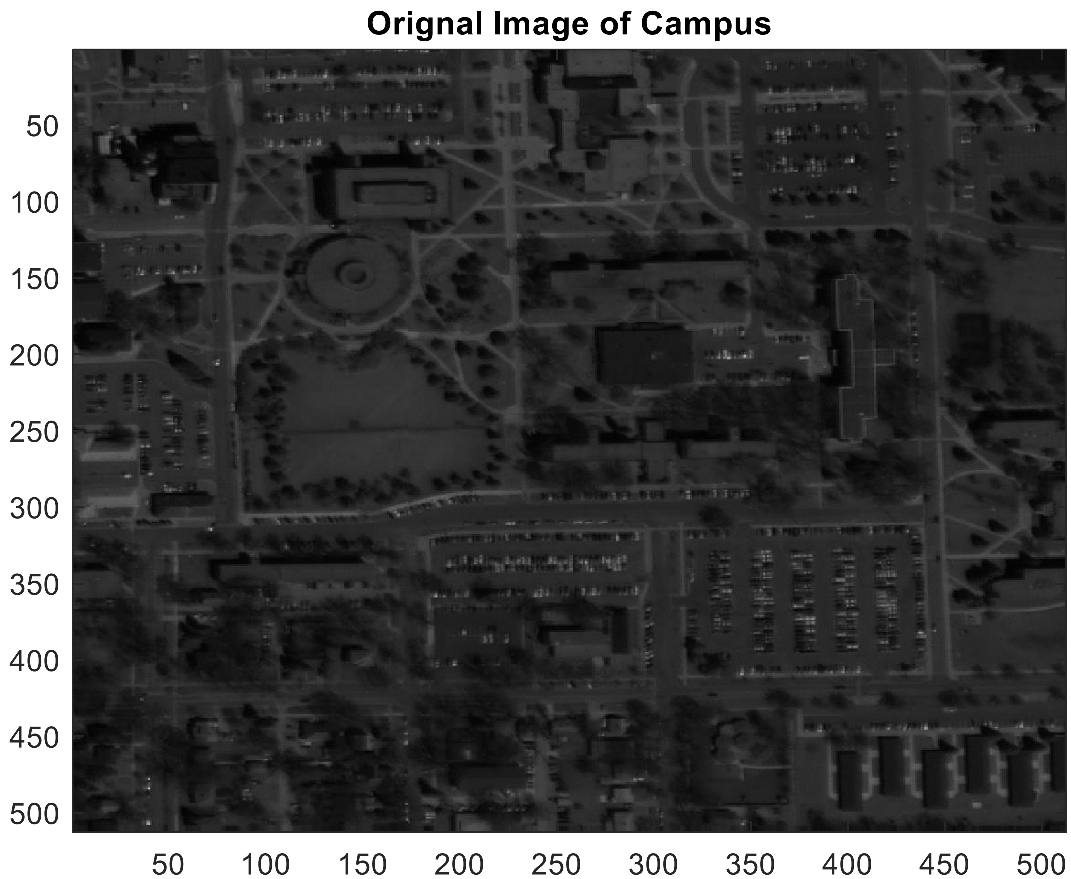

Figure 1: Original image of SDSU campus

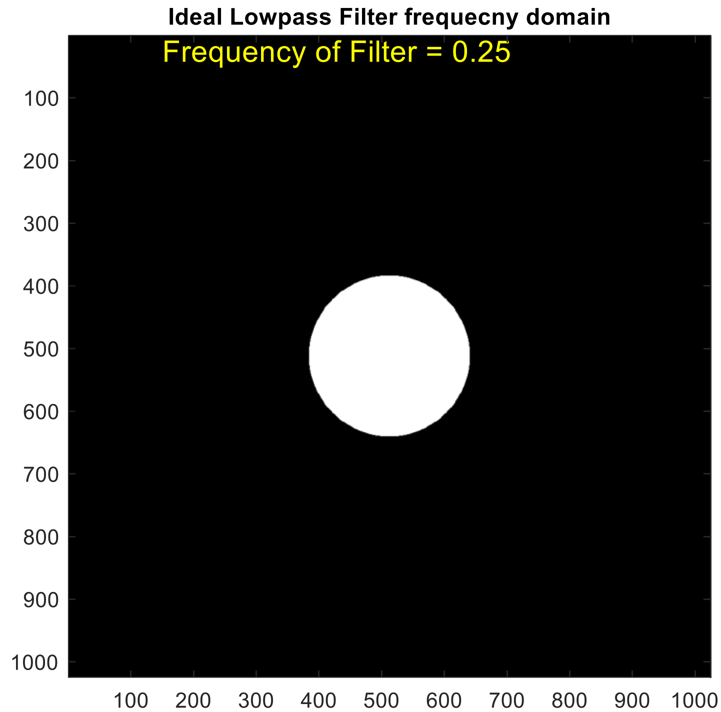

Figure 2: Ideal low pass filter with cut off frequency of 1/4

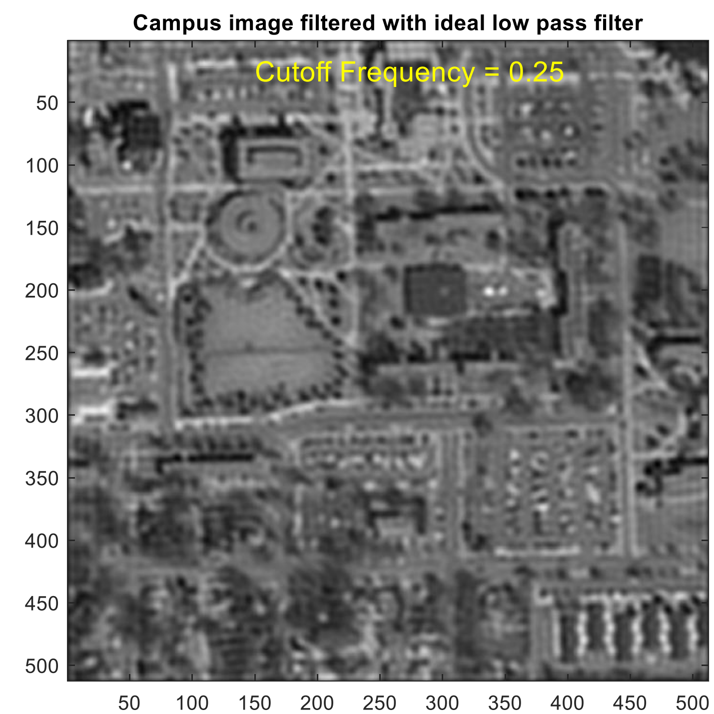

Figure 3: Filtered image with cut off frequency of 1/4

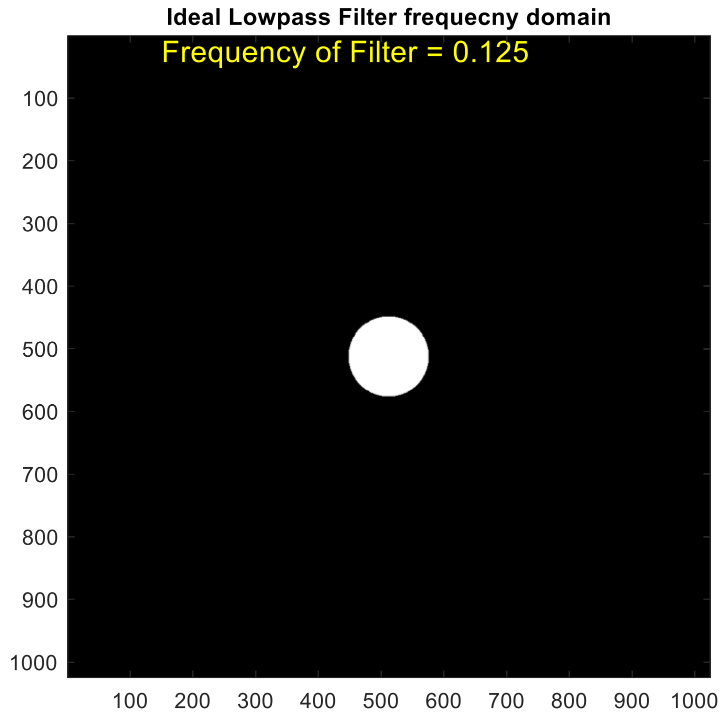

Figure 4: Ideal low pass filter with cut off frequency of 1/8

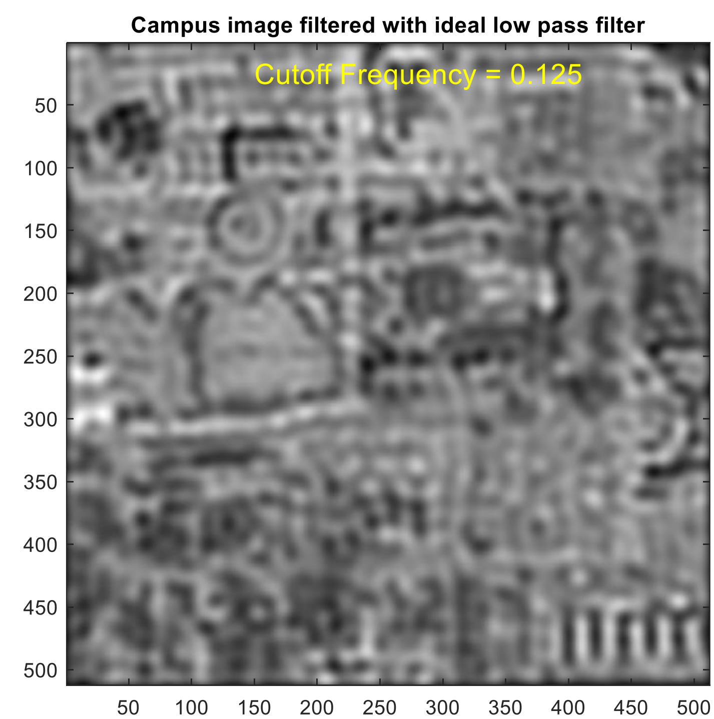

Figure 5: Ideal low pass filter with cut off frequency of 1/8

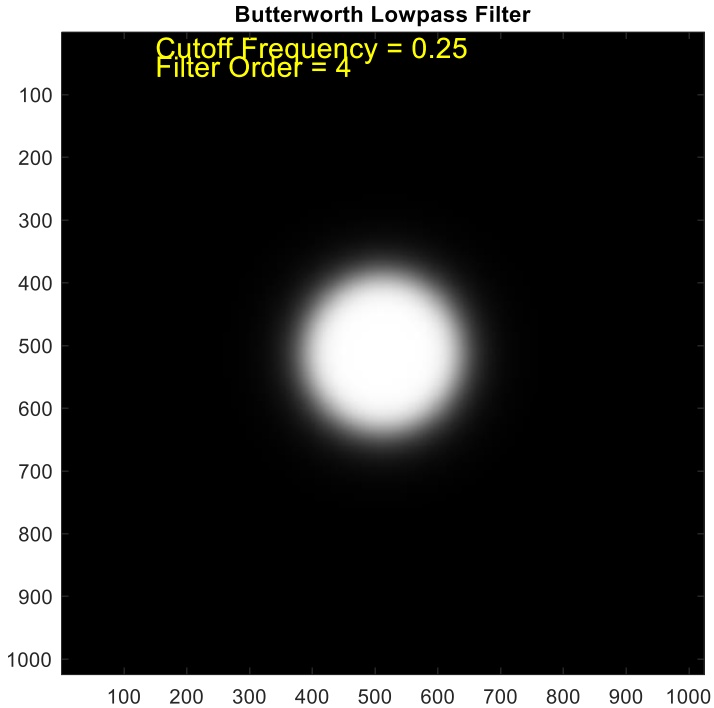

Figure 6: Butter worth low pass filter with cut off frequency of 1/4, order = 4

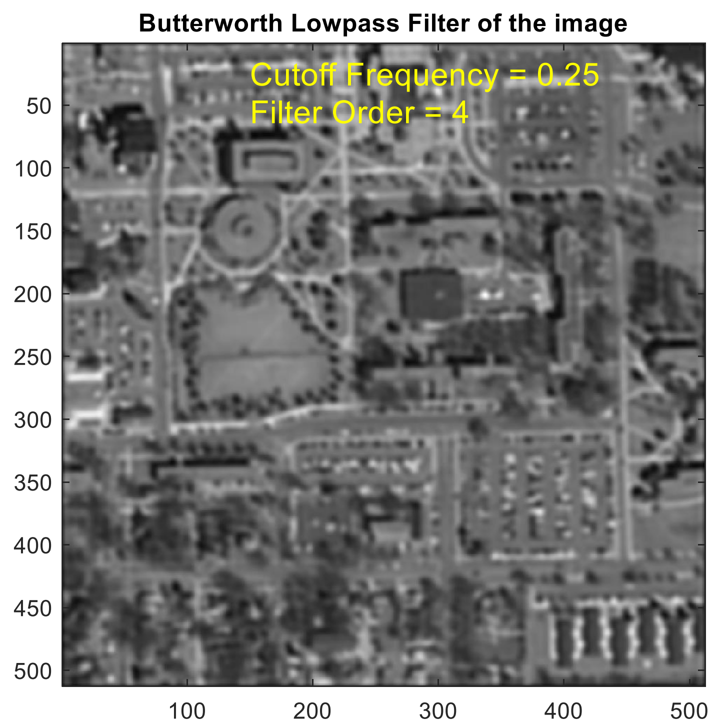

Figure 7: Butterworth low pass filter with cut off frequency of 1/4, order = 4

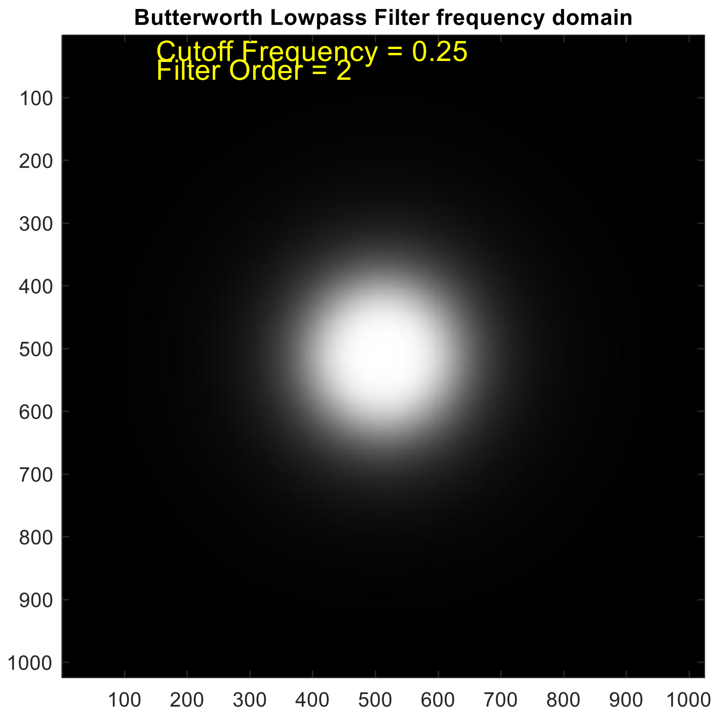

Figure 8: Butterworth low pass filter with cut off frequency of 1/4, order = 2

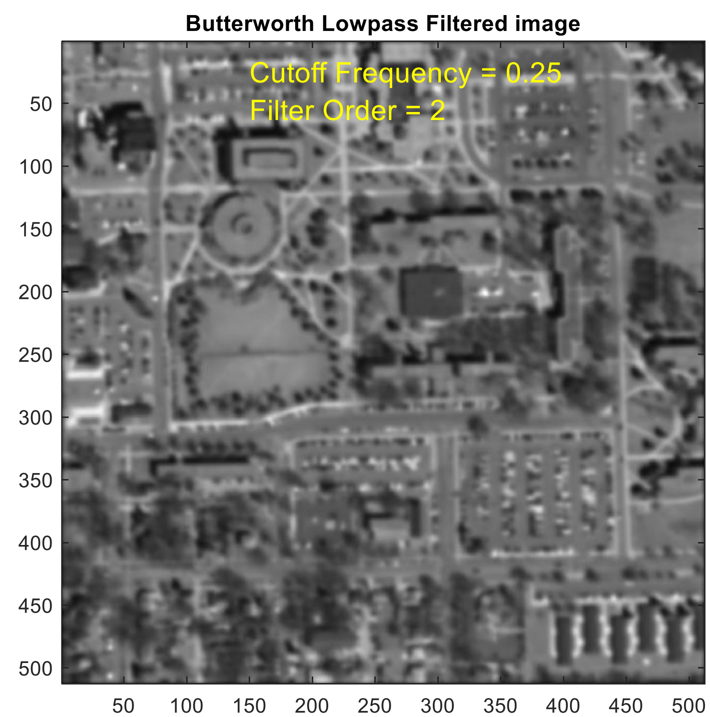

Figure 9: Butterworth low pass filter with cut off frequency of 1/4, order = 2

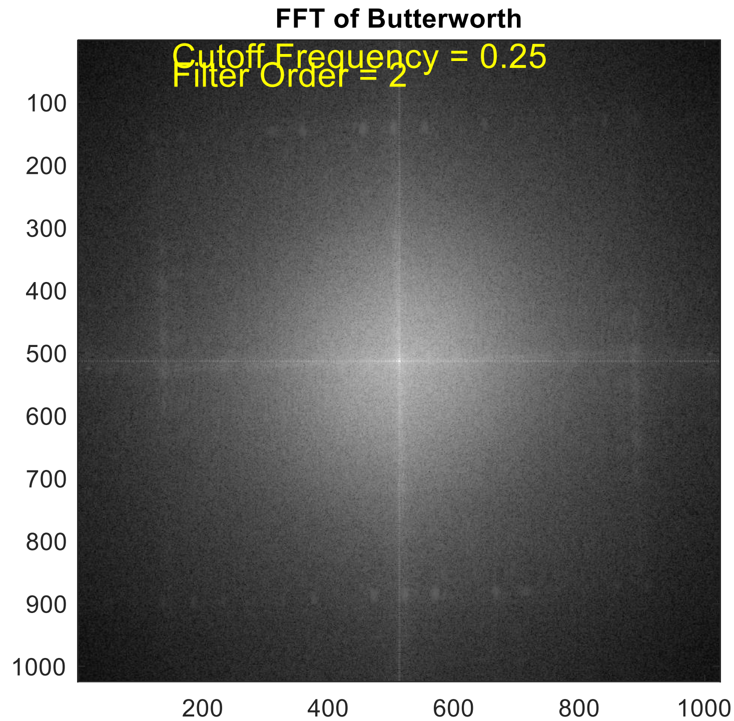

Figure 10: FFT of Butterworth low pass filtered image with cut off frequency of 1/4, order = 2

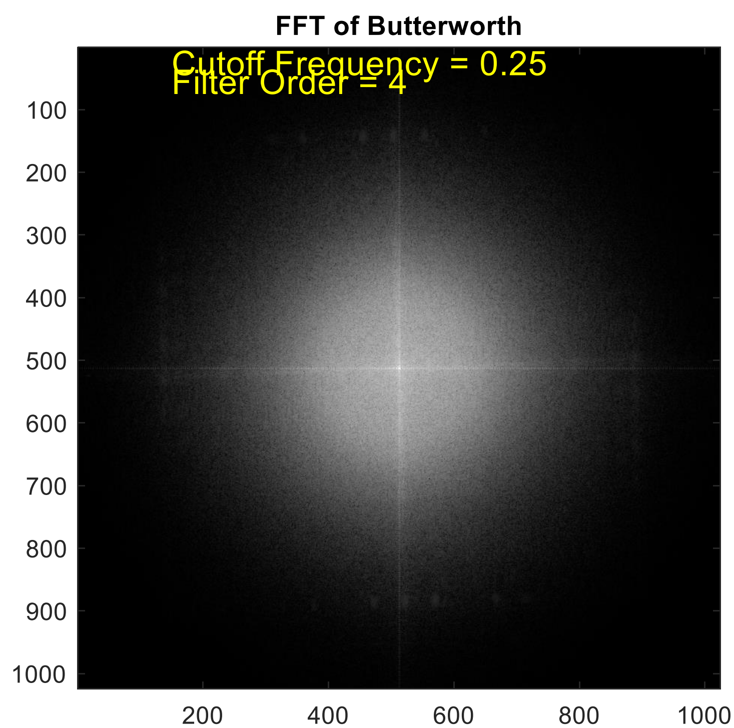

Figure 11: FFT of Butterworth low pass filtered image with cut off frequency of 1/4, order = 4

After low pass filtering, the result was as expected, Fig.3 and Fig.5, as the radius of the low pas filtered decreased the image got blurrier, since more high frequency component was removed from the image.

In case of Butterworth low pass filter, as the order increased, the image got slightly blurrier too, however, the effect was not too pronounced. Even though the difference between both the images were not too evident but after analyzing the Fourier transform of both the filtered images, Fig 10 and Fig.11 (order 2 and order 4), it was noticed that 4^{th} order filter removed more high frequency components than 2^{nd} order filter. With the increase in the order of the Butterworth, Fig.6 and Fig.8, the Butterworth filter low pass filter started looking like an Ideal low pass filter.

On comparing the results of low pass filtering and Butterworth filtering it was noticed that Ideal low pass filter induces ringing in the image and Butterworth filter doesn't.

In theory, ideal low pass filter will always induce ringing in the image, but Butterworth filter won't induce ringing for 1^{st} and 2^{nd} order. However, after analyzing the output image of Butterworth 4^{th} order filter, Fig.7, the ringing in the filtered image was not evident, this was the only result that deviated from theoretical predictions.

For the HPF, test your filter with cutoff frequency of ¼ cycle/pixel for the ideal case and the Butterworth case with order = 4. Test with α = 0 and α = 0.15 for both filter types. Show output images and discuss the effect that each filter had on the image. Generate a summary statement of the effect that α has on the output image.

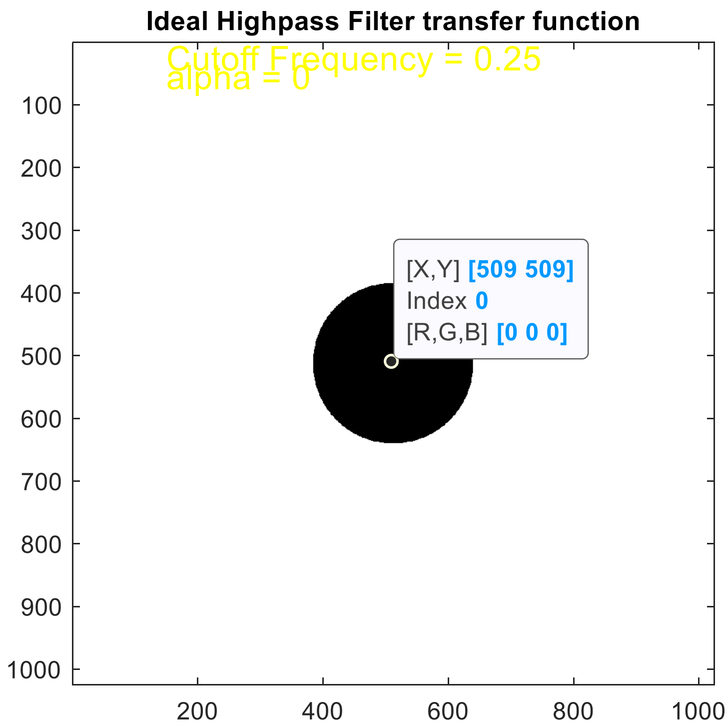

Figure 12: High pass filter's transfer function with cut off frequency of 1/4, a = 0

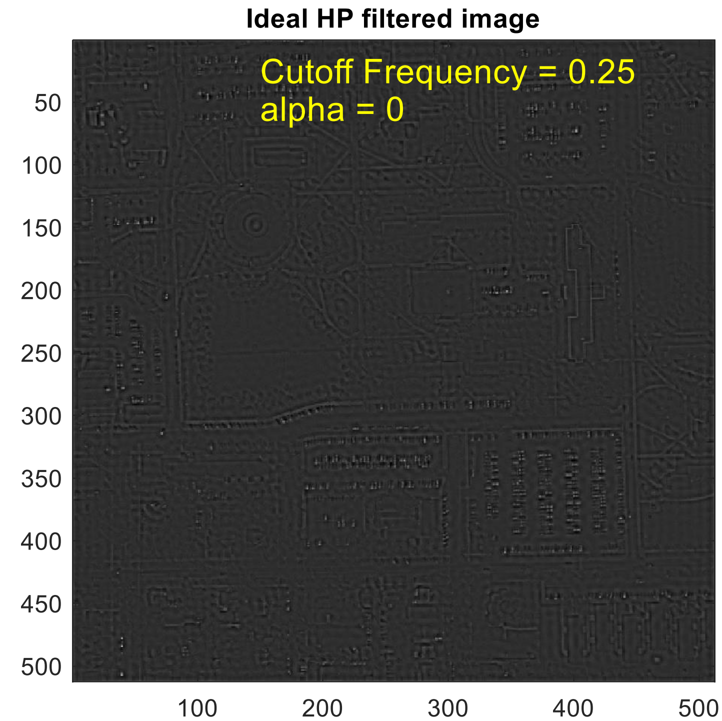

Figure 13: High pass filtered image with cut off frequency of 1/4, a = 0

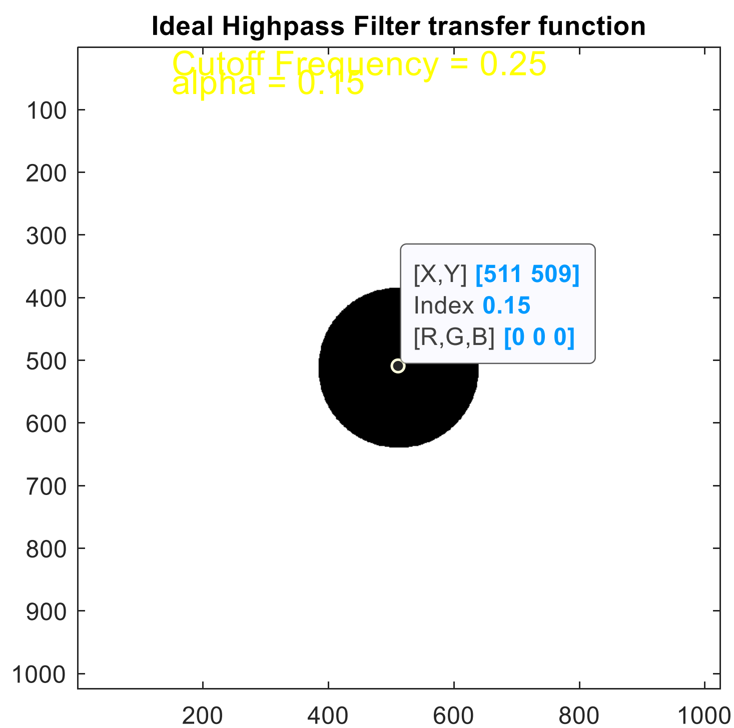

Figure 14: High pass filter's transfer function with cut off frequency of 1/4, a = 0.15

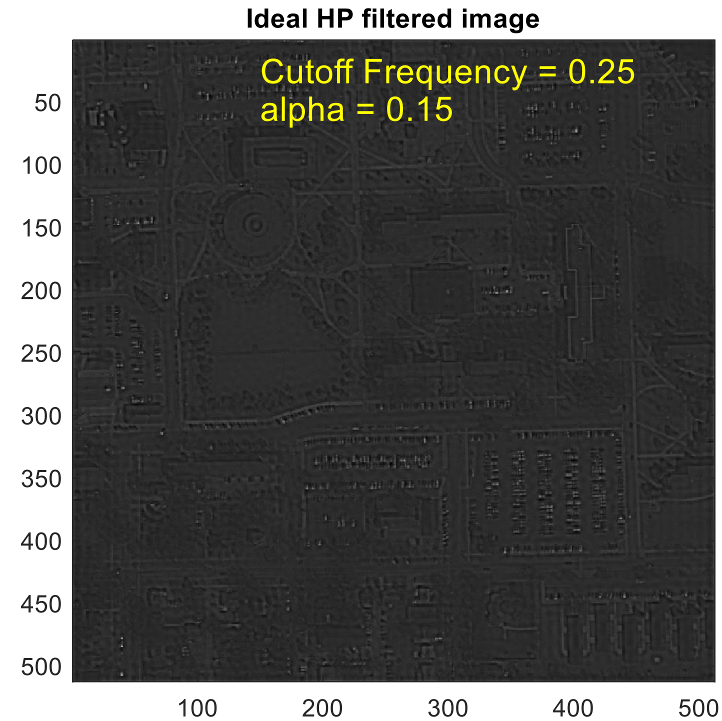

Figure 15: High pass filtered image with cut off frequency of 1/4, a = 0.15

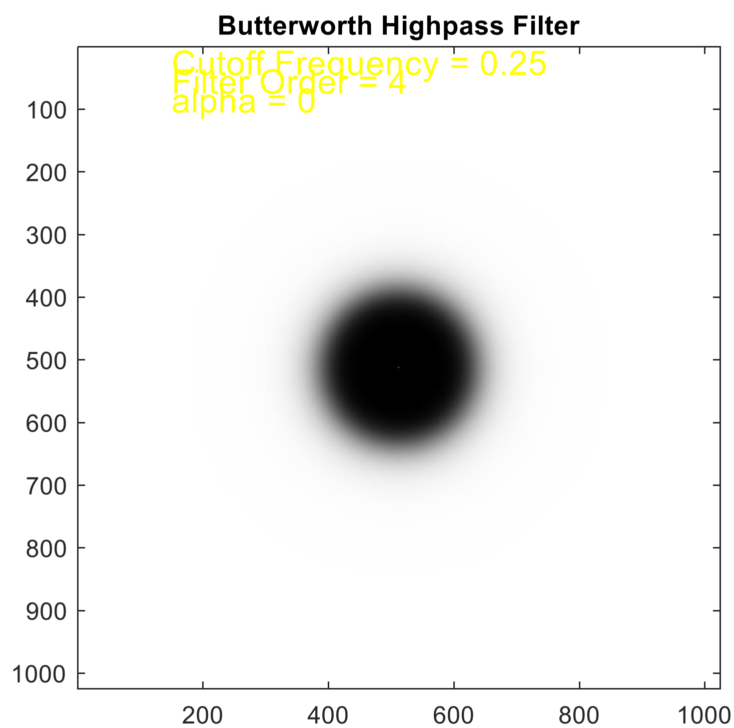

Figure 16: Butterworth High pass filter's transfer function with cut off frequency of 1/4, order = 4, a = 0

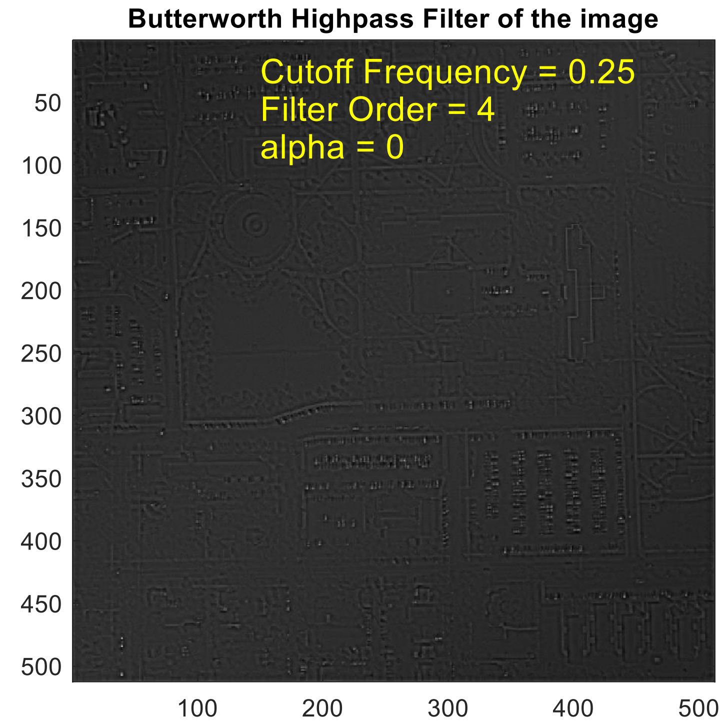

Figure 17: Butterworth HP filtered image with cut off frequency of 1/4, order = 4, a = 0

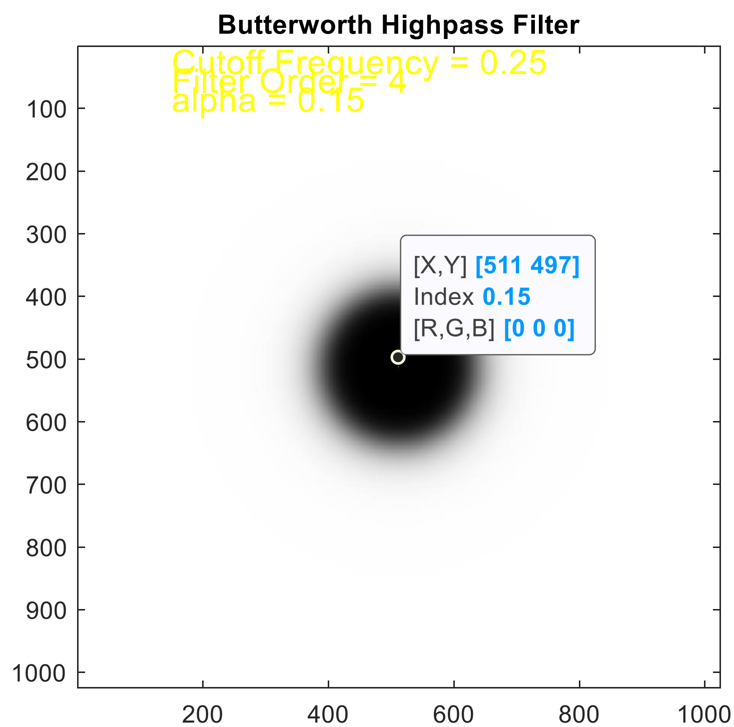

Figure 18: Butterworth HP filter’s transfer function with cutoff freq of 1/4, order = 4, a = 0.15

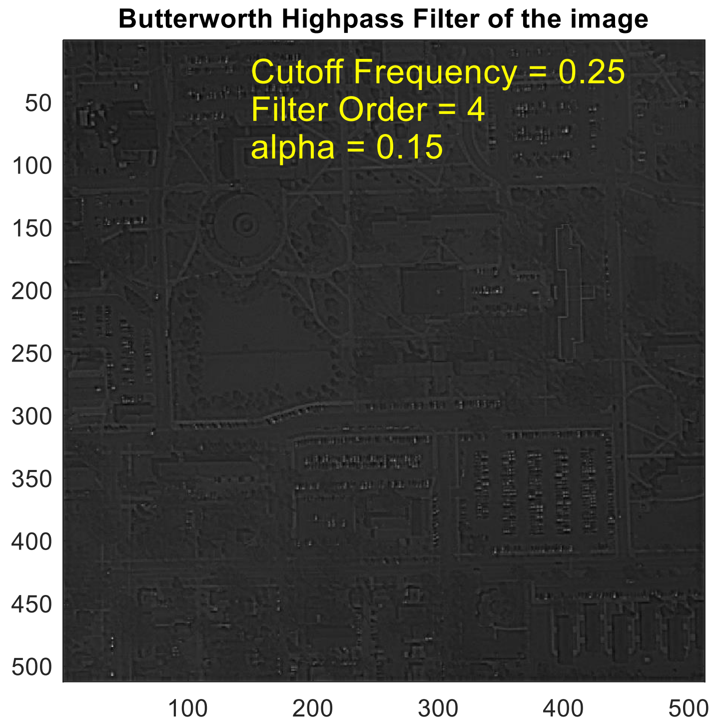

Figure 19: Butterworth High pass filtered image with cut off frequency of 1/4, order = 4, a = 0

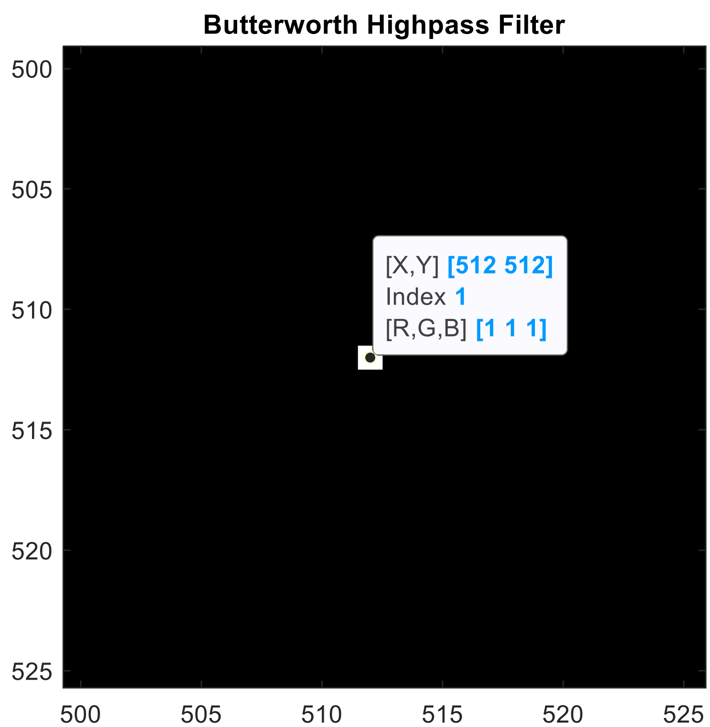

Figure 20: Filter DC value for Butter worth HPF, order = 4, a = 0

We (Me, Gagan and Lin, I also asked Zach about this) struggled with the wording of 1.7, however, according to interpretation, we had set the DC value of all the HPFs to be 1,Fig.20, and scaled the stop band with the scaling factor alpha.

Results were mixed, after high pass filtering (a=0) the image got dark and only edges were preserved/enhanced, Fig.13. Edges were preserved because the HPF filtered out the low frequencies and kept the high frequencies. However, the DC value of the filter was set to 1, hence, it shouldn't filter out the DC component and therefore image shouldn't get dark. We investigated the Fourier transform of the image and found out that the DC value was a small non-zero number. My understanding is that the original image had a low DC value, since it was already dark to begin with. With the increase in alpha (a= 0.15) the filtered image looks brighter, Fig.15, which was expected because low frequencies were now attenuated less now, hence more brightness and contrast.

Butterworth HPF had the same effect, with the increase in alpha value the image got brighter and got more contrast.

On comparing Butterworth filter and Ideal high pass filter, it was noticed that the IHPF induced ringing and Butterworth filter produced smoother images and didn't induce ringing. This was expected.

With the increase in alpha value the image got brighter in both cases, this was also expected.

Calculate the RMSE between the original image and the output image for each case above. Turn in an 'm' file with your function that the instructor can implement on another test image.

Table 1: Root mean square error value for images after using different filters

Filter type	**RMSE**
ILPF with 1/4 cycles / pixel	42.66
ILPF with 1/8 cycles / pixel	62.23
BLPF with 1/4 cycles / pixel, 2^{nd} order	37.97
BLPF with 1/4 cycles / pixel, 4^{th} order	39.95
IHPF with 1/4 cycles / pixels, a = 0	367.14
IHPF with 1/4 cycles / pixels, a = 0.15	312.07
BHPF with 1/4 cycles / pixels, order = 4, a = 0	354.29
BHPF with 1/4 cycles / pixels, order = 4, a = 0.15	301.01

2. Frequency Domain Noise Removal

Remove the distracting noise that is present in **ngirl2.img** and recover Lena as accurately as possible. Show the before and after images. Calculate the RMSE between the original Lena and the filtered **ngirl2.img**. Document the approach you took in the procedure section with a few lines of pertinent Matlab code.

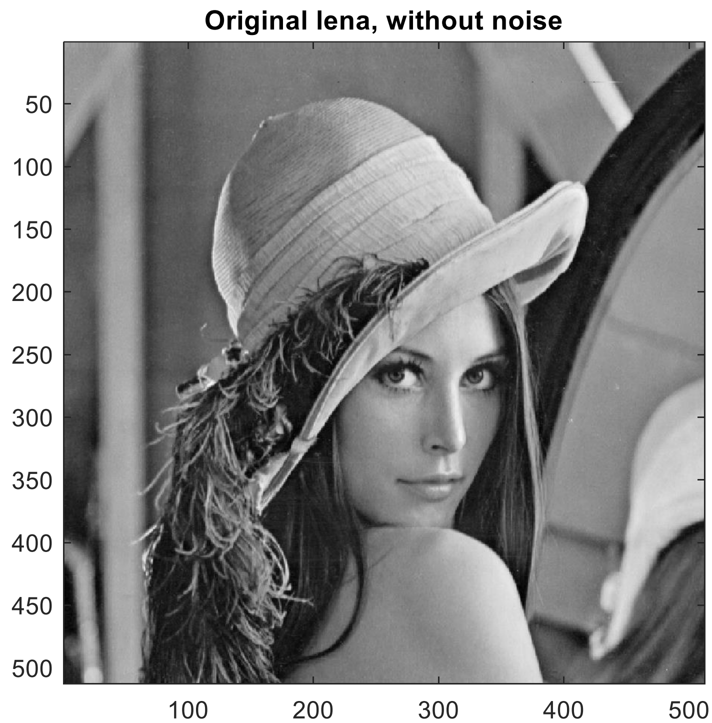

Figure 21: Original Lena image

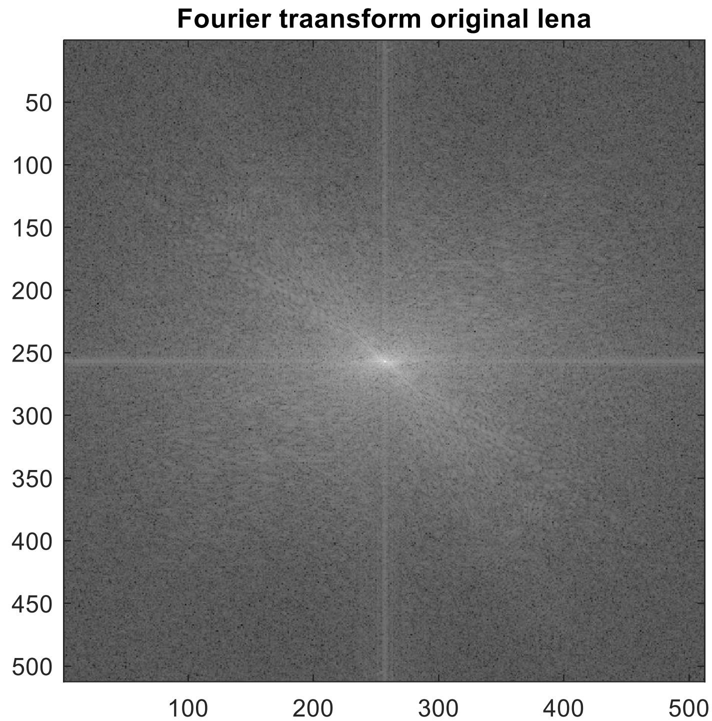

Figure 22: Fourier Transform of Lena

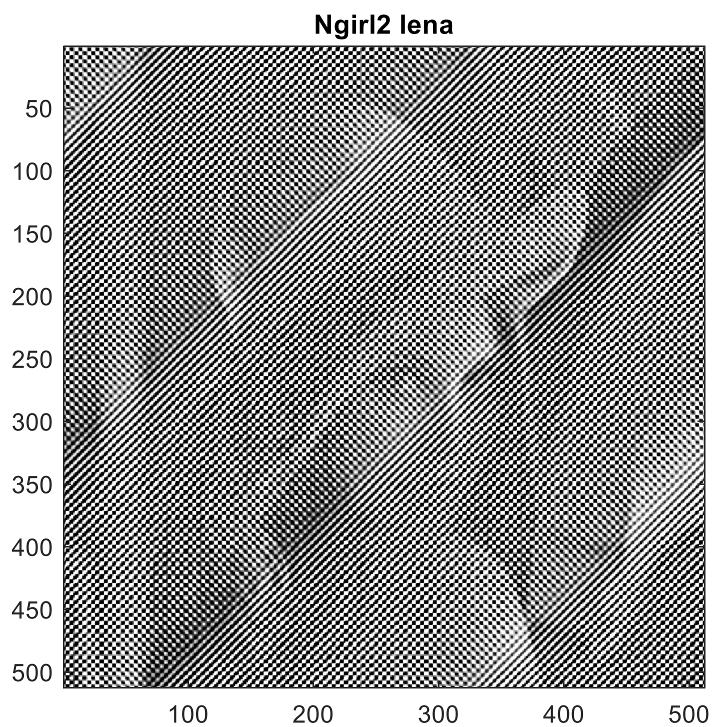

Figure 23: Noisy Lena

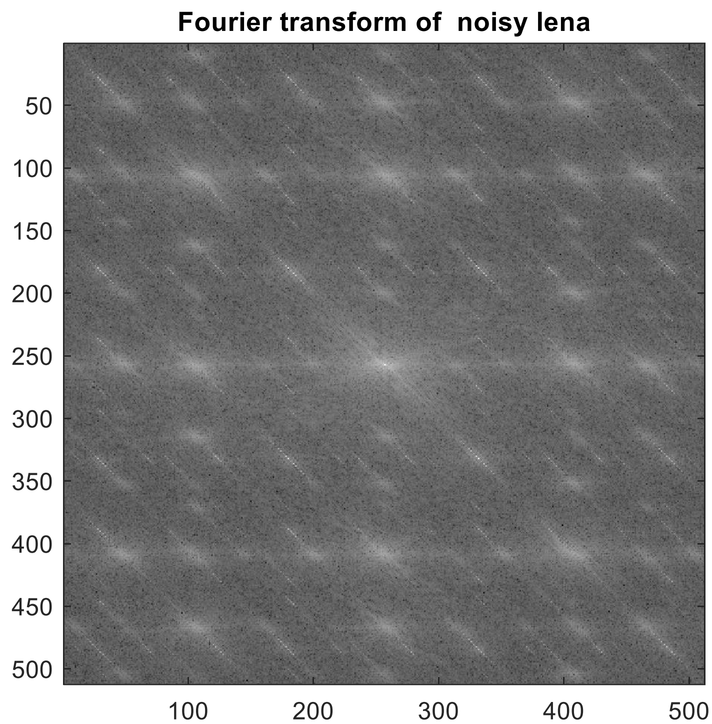

Figure 24: Fourier transform of Noisy Lena

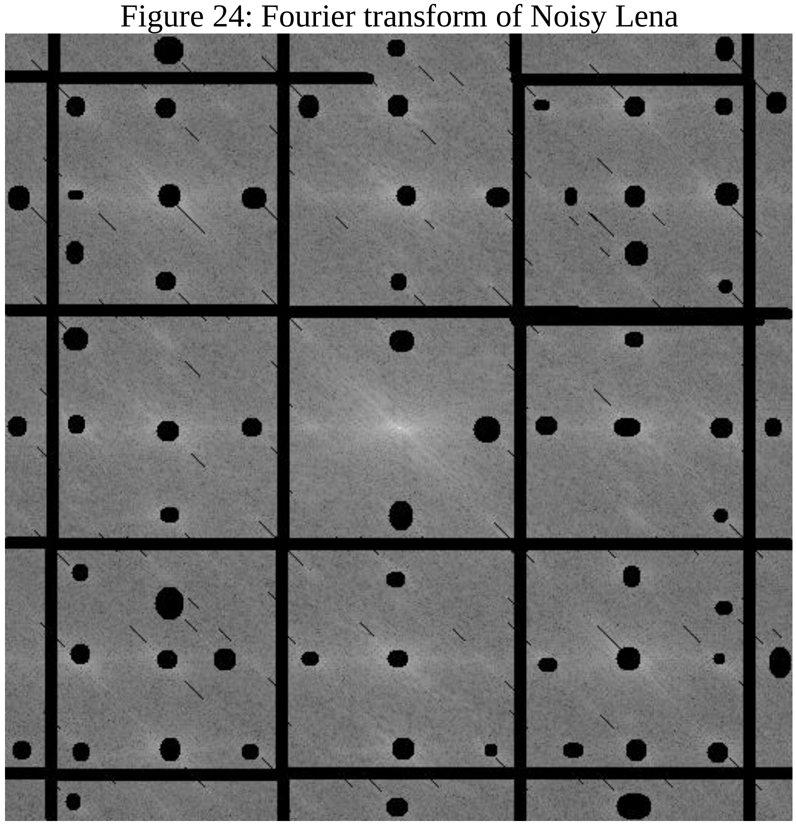

Figure 25: Notch Filtering of Noisy Lena

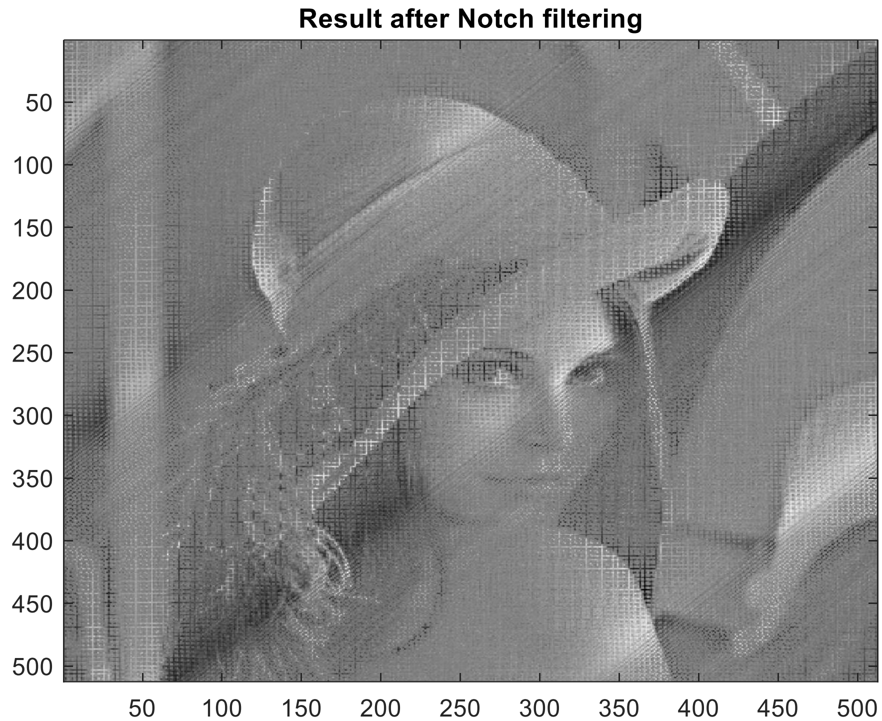

Figure 26: Notch Filtering Result

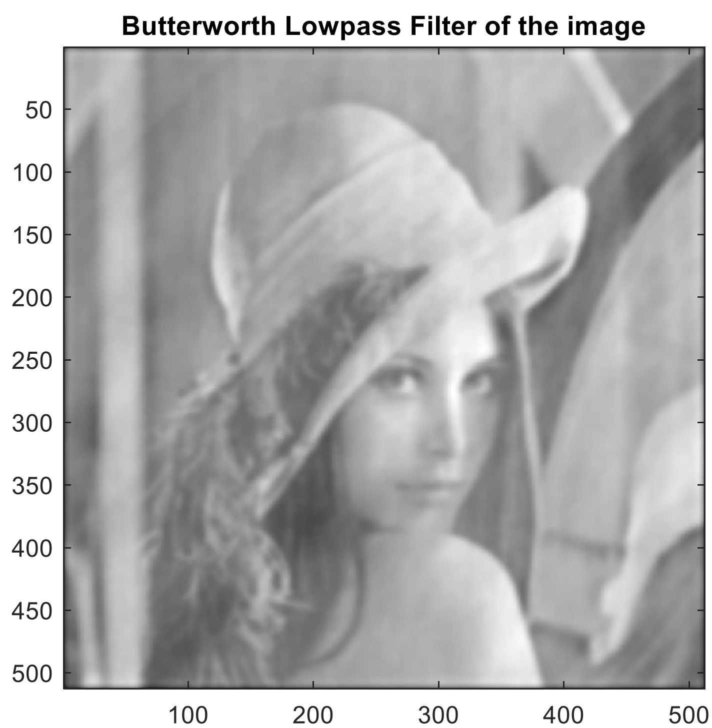

Figure 27: Butterworth Low pass filter

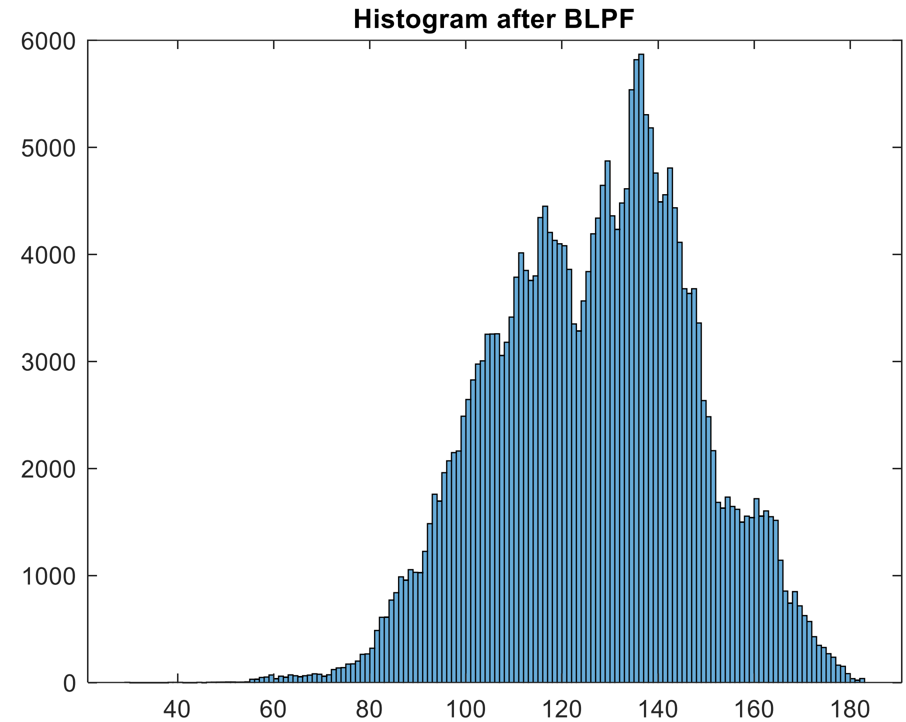

Figure 28: Histogram of Lena after filtering

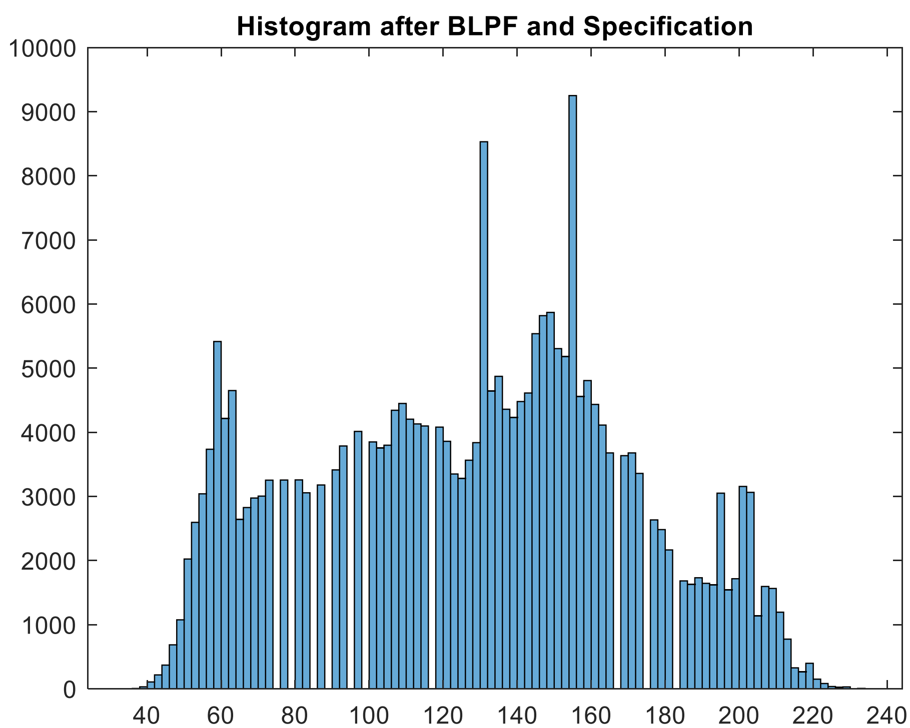

Figure 29: Histogram of Lena after specification

Code: `outputeq = histeq(output,xlena);`

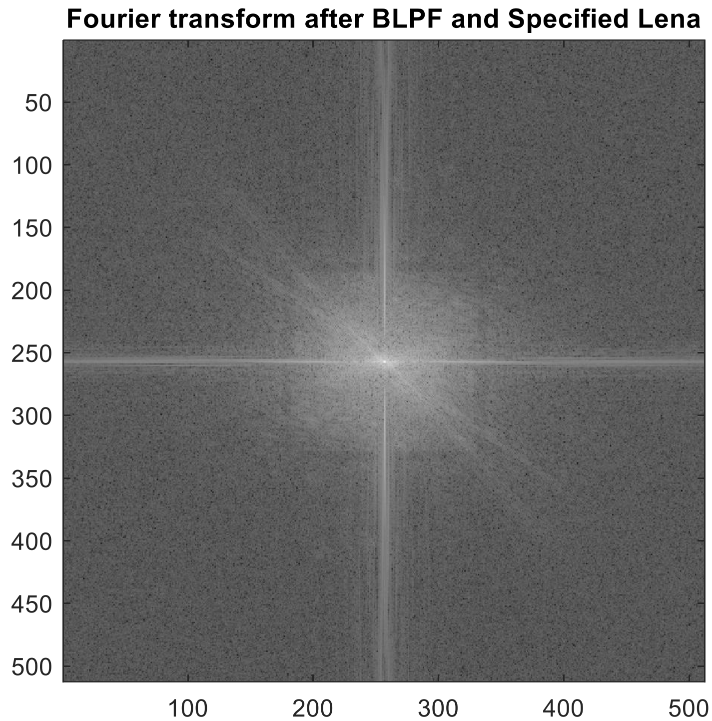

Figure 30: Fourier Transform of specified Lena

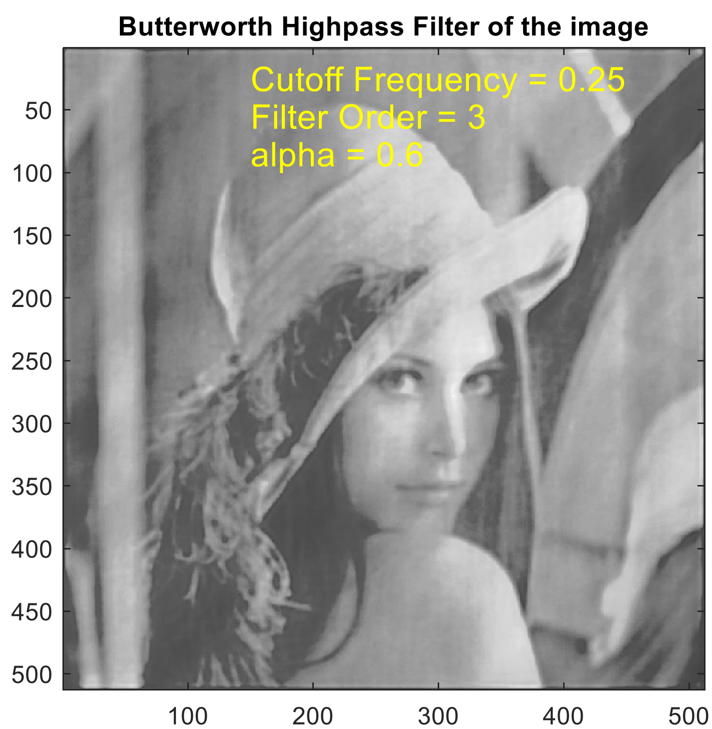

Figure 31: Lena after high pass filtering

Table 2: Root mean square error value for Original Lena vs Filtered Lena

	RMSE
Original Lena vs Filtered Lena	16.74

Code:

```
Lena_rsme = sqrt(immse(outputeq,lena));
```

Procedure and analysis:

First original Lena was downloaded and analyzed, Fig.21, Fourier transform was computed using MATLAB FFT function for the original Lena, Fig. 22. Then Fourier transform was computed for noisy Lena and was compared with the original Lena, Fig.24. On comparison it was noticed that noisy Lena has a periodic noise in it, which looked like one our book discusses. Hence, a notch filter was constructed, using paint, Fig.25, and the noise was notched off. Later, Lena was analyzed again after using the notch filter, however, there was still some diagonal and periodic square kind of noise present in Lena, Fig.26.

After intensive research about the kind of noises and filtering techniques, it was concluded that it would be better to smooth out the noise using a Butterworth Low pass filter. After smoothing out the noise, Fig. 27, a histogram analysis was done on Lena and was noticed that Lena does not have low intensity values. Hence, a histogram specification was done using the original Lena and then a Butterworth HPF was used to smooth out excessive contrast, Fig.31.

Write a brief conclusions section that is a summary of what you have learned in this project and how theory compares with experimental results.

Conclusion:

In part 1 of the project I learned that low pass filter can be used to smooth out edges and get rid of high frequency noise, however, ILPF induced ringing hence it is better to use Butterworth Low pas filter to avoid ringing. However, a higher order Butterworth filter(n>2) can induce ringing too, but it was not noticed in the result.

In high pass filtering part, I learned that the DC and close to DC frequencies contribute to overall intensity of the image. Hence, when sharpening the edges, its better to preserve the DC and close to DC component so that the overall image intensity can be preserved, and image doesn’t turn bright.

In Part 2 I learned about periodic noise and how a notch filter can be used to remove the noise, which also confirms what I read in the book. I also learned on how different techniques can be used and combined to produce desired result.

References

https://www.youtube.com/watch?v=ytW8RnH3Pow&t=442s