Assignment 2 - Coded Apertures

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1 Blur simulation and recover of focused image

1.1 Impact of Noise Levels and blur sizes

We imported an image, simulated the blur effect and recovered the focused image; in order to see the noise and blur effect we created vector two vector with different range of values, for σ we implemented $sigma\_v = [0.001, 0.01, 0.05]$ and for blur $blurSize\_v = [5, 13, 25]$. Since noise is additive, when we attempt to recover the image using deconvolution, the noise term is also divided by PSF in the frequency domain.

We have contrasted low versus high σ fixing the blur, with low σ the reconstruction is relatively clean. The Wiener deconvolution can effectively balance the inversion without amplifying too much garbage data, as is shown in the figure 1.

Figure 1: σ = 0.001 & Blur size = 5 image

With high σ we notice a significant amplification of noise, often appearing as grain or snow across the image, as we can appreciate in the figure 2.

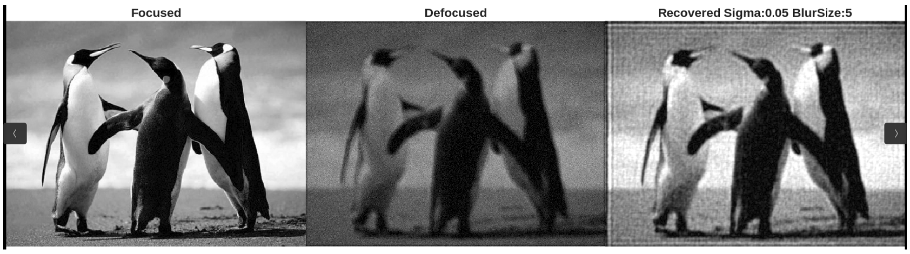

Figure 2: σ = 0.05 & Blur size = 5 image

As noise increases, the deconvolution process must become more conservative to avoid dividing by small values in $\mathcal{F}[k]$, which would explode the noise. This usually results in a smoother but blurrier recovered image because high-frequency details are indistinguishable from noise.

Now in order to see the impact of blur we have done the opposite, fixing σ and testing with small and large values of blur.

Figure 3: $\sigma = 0.001$ & Blur size = 25 image

The blur size determines the diameter of the PSF (k). In a circular aperture, a larger blur size corresponds to a larger disk in the spatial domain, When we set a small blur, the PSF is close to a delta function (a single point). The frequency response $\mathcal{F}[k]$ is relatively flat, meaning fewer frequencies are lost. Reconstruction is usually very high quality, as it is shown in the figure 1.

On the other hand, for a large blur size, the PSF covers a larger area. In the frequency domain, a larger spatial disk results in more zero-crossings (singularities) in the power spectrum. in the figure 8 we can see strong ringing artifacts and loss of fine texture.

1.2 Impact of different deconvolution algorithms

For this experiment we used the same values, but we focused on the variation of the noise and how each algorithm handle it. Thus, after running the three algorithms, Wiener with Priors, Wiener without Priors, and Richardson-Lucy we have seen a difference notable when set $\sigma = 0.01$.

With the Wienner with priors algorithm, the ringing artifacts (the horizontal lines at the top) are very visible because of the circular aperture, but we can observe in the figure 4 that this is significantly cleaner than the version without priors. The natural image prior helps the algorithm recognize that the grain is noise and should be suppressed. On the other hand, with the Wiener without Priors, the image 5 is compltetly broken it appears nosily with a lot of grains, to fix this, we would need to increase the NSR (Noise-to-Signal Ratio) parameter in deconvwnr function.

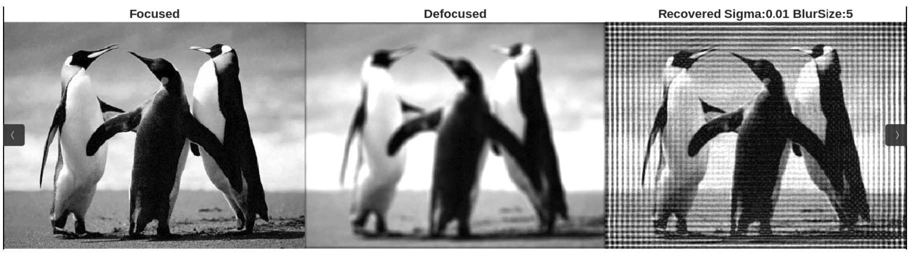

Figure 4: Circular aperture, Algorithm: Wienner with priors, $\sigma = 0.01$ & Blur size = 5 image

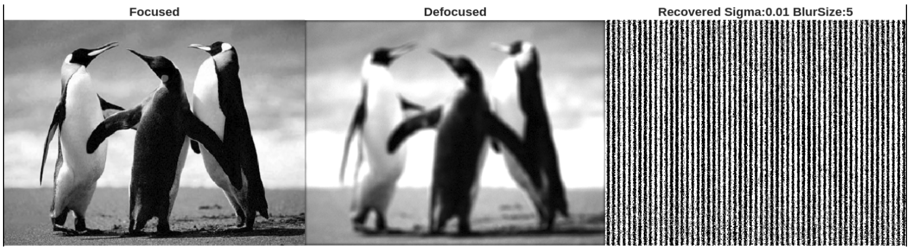

Figure 5: Circular aperture, Algorithm: Wienner without priors, $\sigma = 0.01$ & Blur size $= 5$ image

For the Richardson-Lucy algorithm in comparison to the Wiener filter without priors, the current method produces a softer noise distribution. However, this is offset by an increase in the halos or thick, wavy ripples around the penguins, a common limitation of iterative deconvolution in the presence of higher noise levels.

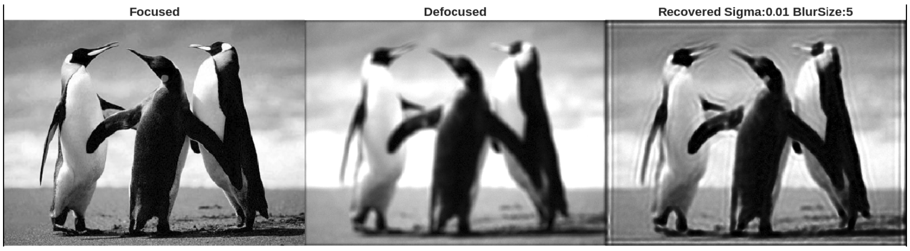

Figure 6: Circular aperture, Algorithm: Lucy, $\sigma = 0.01$ & Blur size $= 5$ image

2 Power spectra

The image 7 with blur size 1 shows a clear peak in the frequency domain. This suggests that most of the frequencies are preserved in the signal, meaning that the blur effect is minimal and the image retains more high-frequency details.

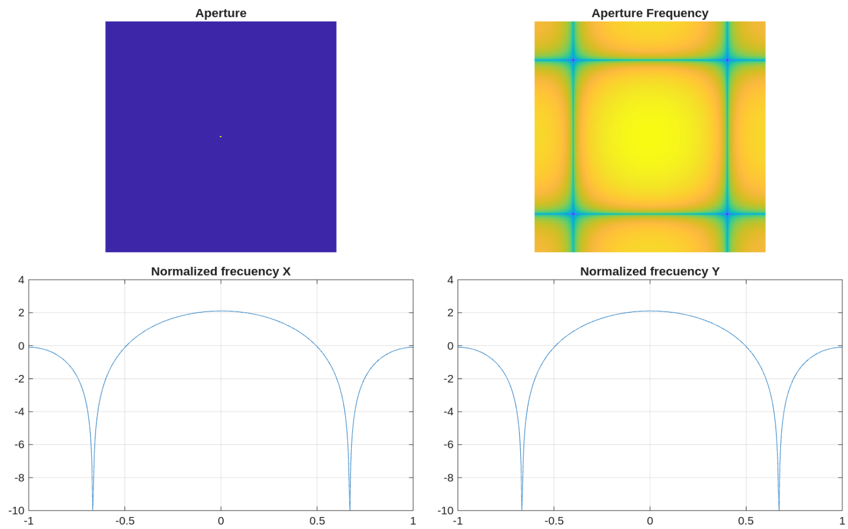

Figure 7: Circular aperture $\sigma = 0.005$ & Blur size $= 1$ image

For a blur size 14 the power spectra of this image 8 show a more significant spread and reduction in the amplitude, especially in the Defocused X and Defocused Y spectra. This suggests that as the blur size increases, more high-frequency details are lost.

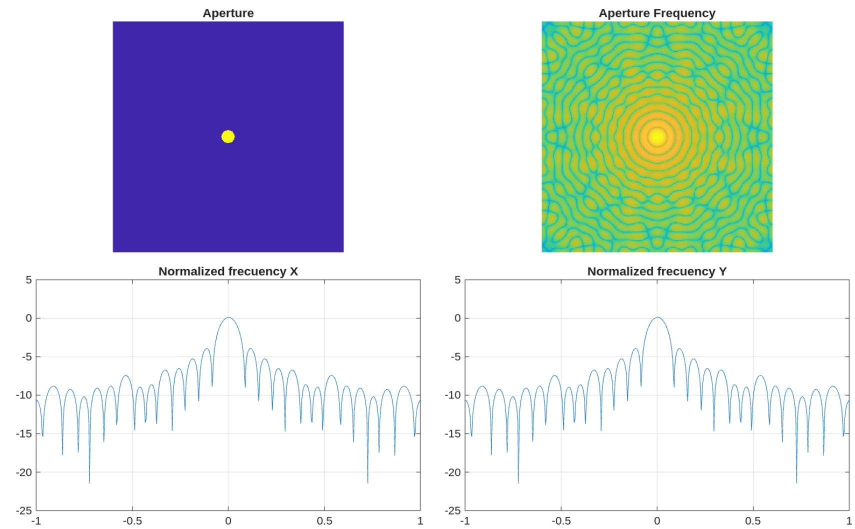

Figure 8: Circular aperture $\sigma = 0.005$ & Blur size = 14 image

In the figure 9 the power spectra of original and defocused images at different blur levels, here we can confirm which for higher blur sizes, we would typically see more energy concentrated in lower frequencies, with high frequencies being progressively attenuated.

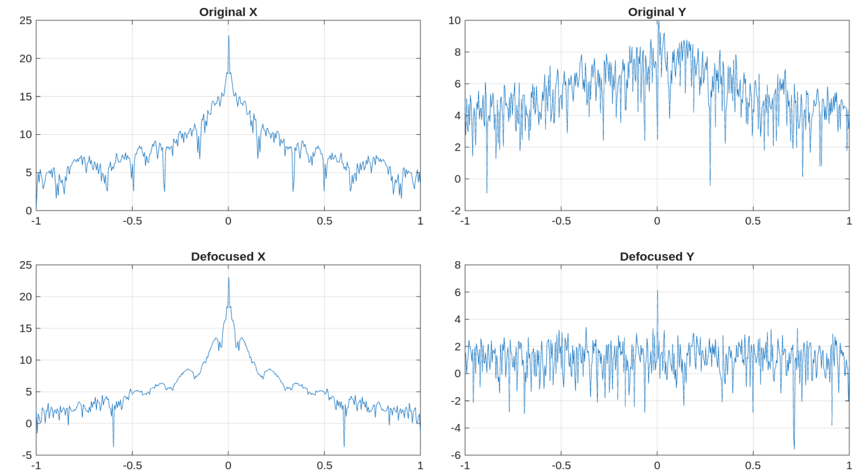

Figure 9: Circular aperture $\sigma = 0.005$ & Blur size = 14 image

Finally, The circular aperture acts as a low-pass filter with the zeros in it. While low frequencies near the center of the spectrum are generally preserved, high-frequency details are removed, the effect in the image is the loss of fine textures and sharp edges.

3 Coded apertures

The introduction of codes apertures in the imaging pipeline can be used for deblurring and for estimating depth from defocus images as it is incoded in the blurr pattern. In this case, the use of Raskar or Zhou apertures allow to recover high frequencies better than with the circular aperture as seen on figure 10.

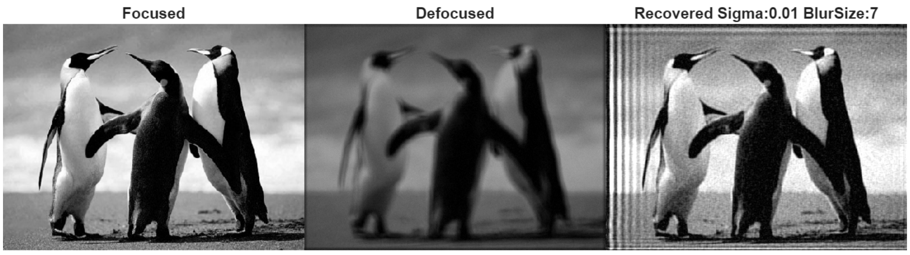

Figure 10: Zhou aperture $\sigma = 0.01$ & Blur size $= 7$ image

Here the influence of the blursize makes a difference where the greater the blursize, the PSF gets more complex and keeps more values in different frequencies, which lets to recover more detail. The Raskar and Zhou apertures avoid zeros in the frequency domain, which allows the deblurring to be a well conditioned problem, as can be seen in figures 11 and 12

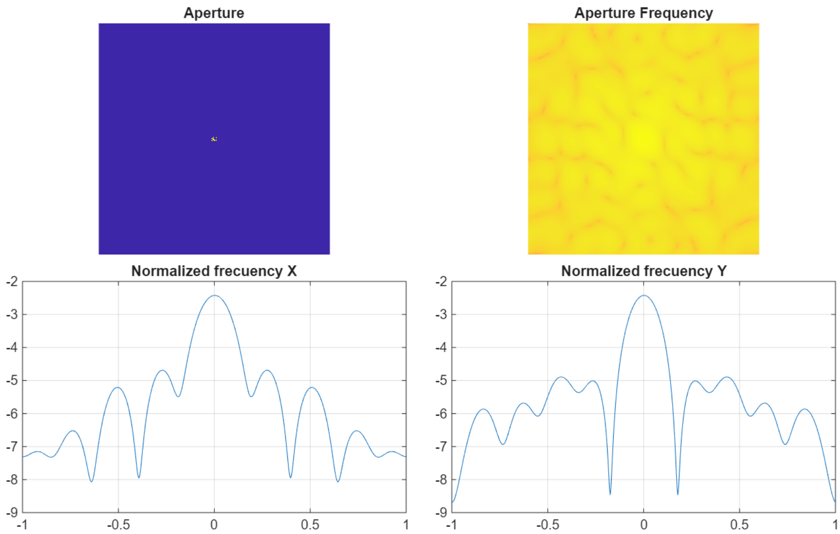

Figure 11: Raskar aperture $\sigma = 0.01$ & Blur size $= 7$ aperture spectrum

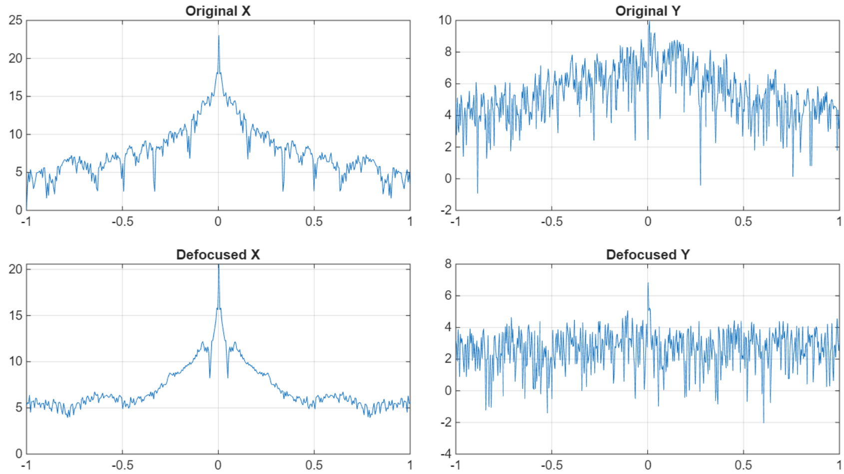

Figure 12: Raskar aperture $\sigma = 0.01$ & Blur size = 7 image spectrum

4 Color images

Lastly, to enable the use of color on the image we needed to perform the same actions but on the 3 channels of the image, so we needed to modify the functions zDeconvWNR and zDefocused. Reaching to this final result in figure 13.

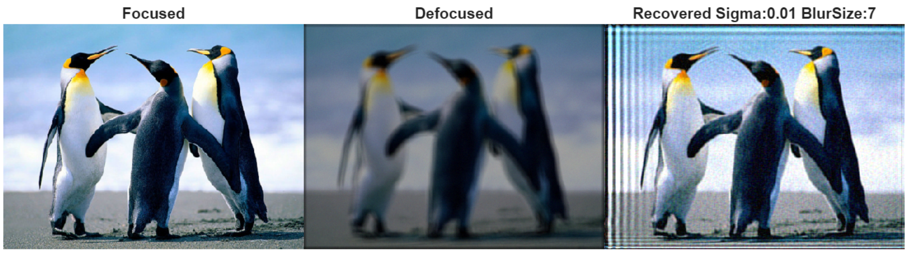

Figure 13: Zhou aperture $\sigma = 0.01$ & Blur size = 7 color image