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# Assignment 2: Coded Apertures

## Blur simulation and recover of focused image

### Sigma experiments (Noise Level)

Experiments were conducted by varying the *sigma* parameter (Gaussian noise) using values between 0.0005 and 0.5.

**Observations:**

- Lower *sigma* values result in a less noisy defocused image, making the recovery process more accurate.
- Higher *sigma* values introduce more noise, which complicates the deconvolution process, generating artifacts and reducing the quality of the recovered image.
- However, **if *sigma* is too low**, the estimated point spread function (PSF) becomes less representative of the actual blur, as it assumes an unrealistically sharp transition. This leads to instability in the deconvolution process, amplifying small errors and introducing artifacts such as ringing or over-sharpening in the recovered image.

### BlurSize experiments

Different blur sizes were tested with values between 1 and 15.

**Observations:**

- Larger blur sizes lead to a blurrier image, increasing data loss in the defocusing step. This lost data cannot be recovered during deconvolution and appears as black lines in the final result.
- Smaller blur sizes result in less data loss, leading to better image recovery.

### Other deconvolution methods experiments

In addition to the Wiener-based method with a natural prior (*zDeconvWNR*), two other methods were tested:

- **deconvlucy:** An iterative method based on the Richardson-Lucy deconvolution algorithm. Tested with different iteration numbers:
    - **1, 3, 10, 30, 80, 150 iterations**
- **deconvwnr:** Wiener deconvolution method without a prior, tested with different *sigma* values.

**Observations on deconvlucy (Effect of Iterations)**

- With a **low number of iterations (1-3)**, the image remains blurry, as the algorithm has not yet sufficiently corrected the blur.
- As the **number of iterations increases (10-30)**, details become sharper, and the image appears more focused.
- However, with **too many iterations (80-150)**, noise and ringing artifacts become prominent. This happens because the algorithm amplifies small errors in the data, leading to overfitting to the noise rather than reconstructing the original image.

**Observations on deconvwnr (Effect of Sigma Change)**

- With **low *sigma* values**, the method assumes that the noise level is minimal. As a result, it performs strong deconvolution, but this can lead to excessive sharpening and ringing artifacts.
- With **moderate *sigma* values**, the method effectively suppresses noise while maintaining detail, leading to the best recovery results.
- With **high *sigma* values**, the algorithm assumes too much noise, which results in excessive smoothing. This removes noise but also blurs fine details, making the recovered image look softer than desired.

# Power spectra

A power spectrum analysis was performed to compare frequency preservation in convolution:

- **Circular aperture:** Some frequencies are attenuated, causing ringing artifacts in the recovered image.
- **Coded apertures:** The apertures proposed by Zhou and Raskar were tested. Both showed better frequency preservation, resulting in fewer artifacts and higher detail in the recovered image.

# Color images

To extend the implementation to color images, each channel (RGB) was processed independently.

**Implementation steps:**

1. The original image is split into red, green, and blue channels.
2. Each channel undergoes the blur and deconvolution process using the same PSF and noise parameters.
3. The recovered channels are merged to form the final color image.

This approach ensures that the recovery quality is maintained across all channels while preserving color fidelity in the final result.

# Figures

sigma = 0.0005

sigma = 0.005

sigma = 0.05

sigma = 0.5

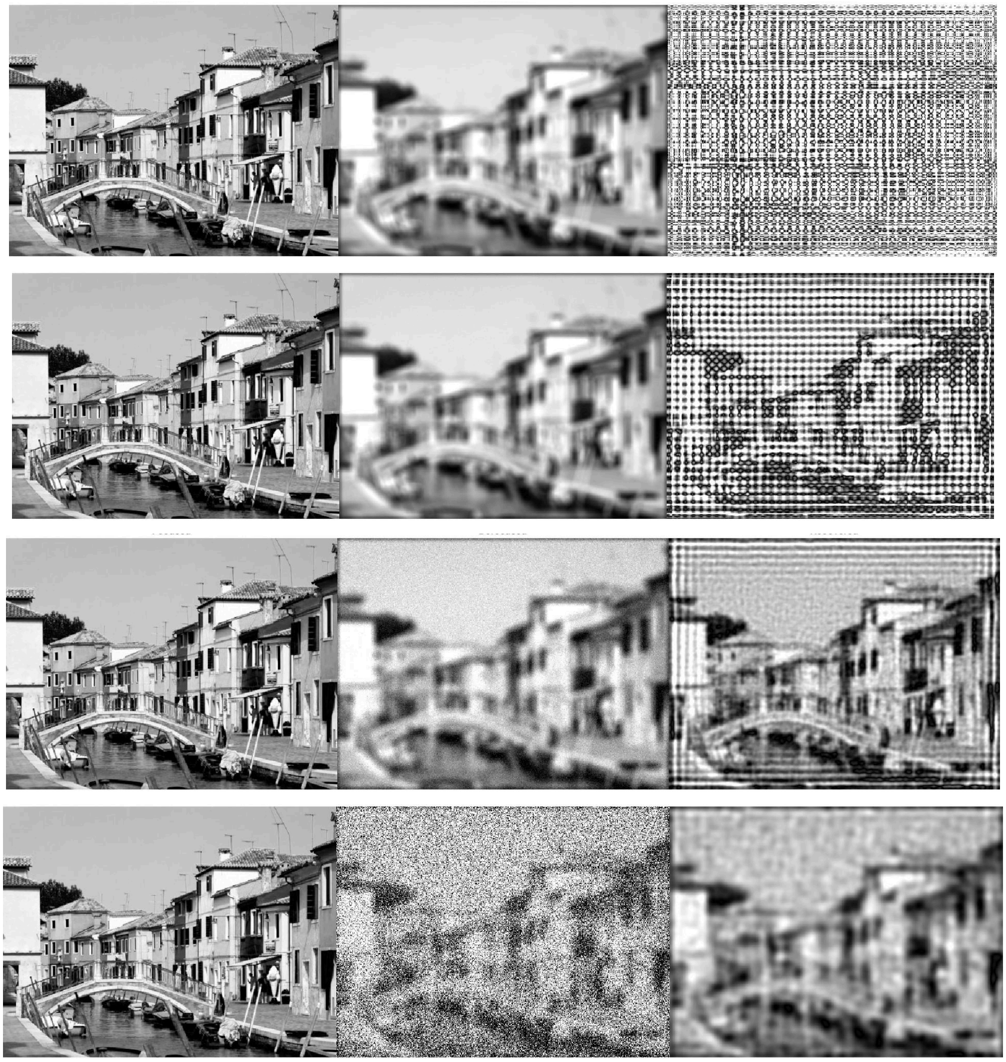

Figure 1: Different experiments with blurSize constant and variable sigma

blurSize = 1

blurSize = 3

blurSize = 7

blurSize = 15

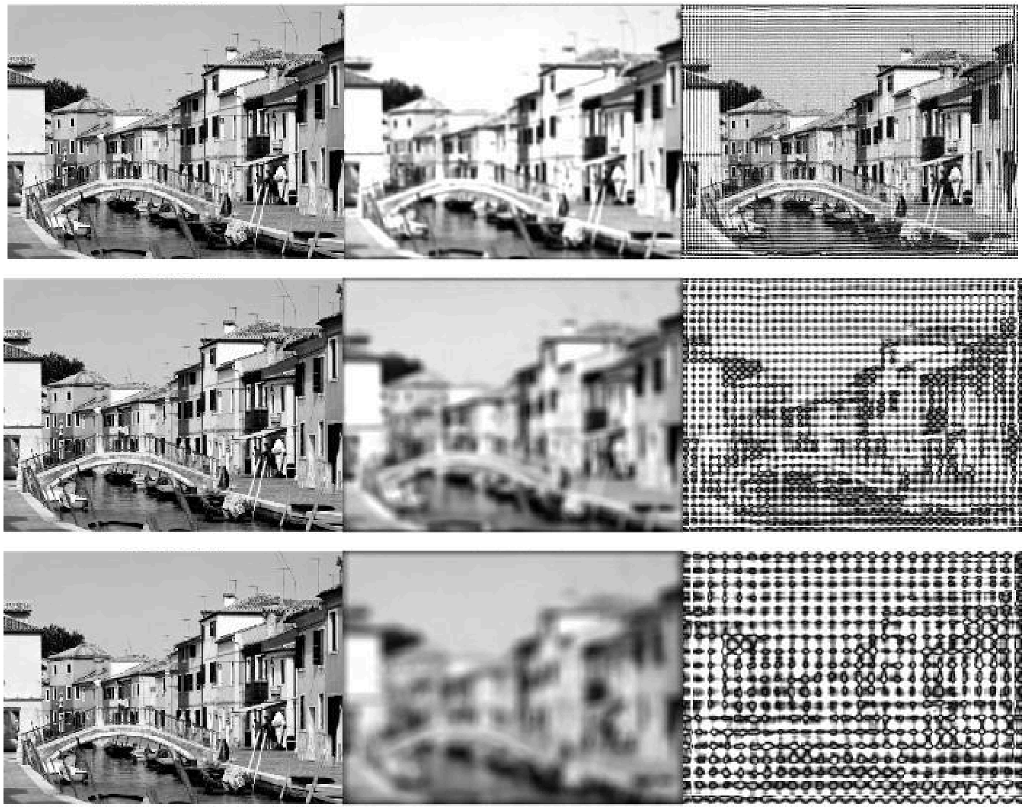

Figure 2: Different experiments with sigma constant and variable blurSize

1 iter

3 iter

10 iter


Figure 3: Different experiments with deconlucy with variable iterations

sigma = 0.5

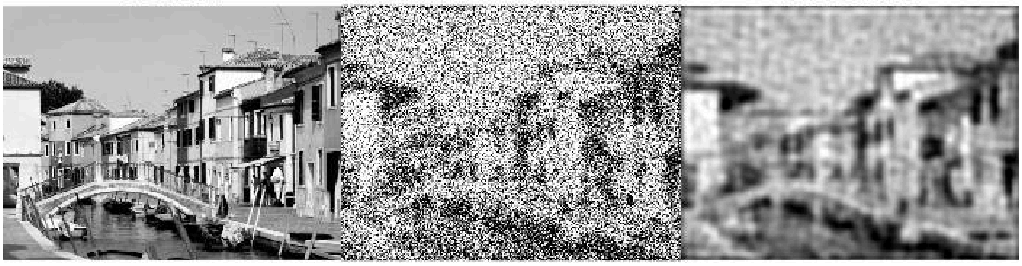

Figure 4: Different experiments with deconvwnr with variable sigma

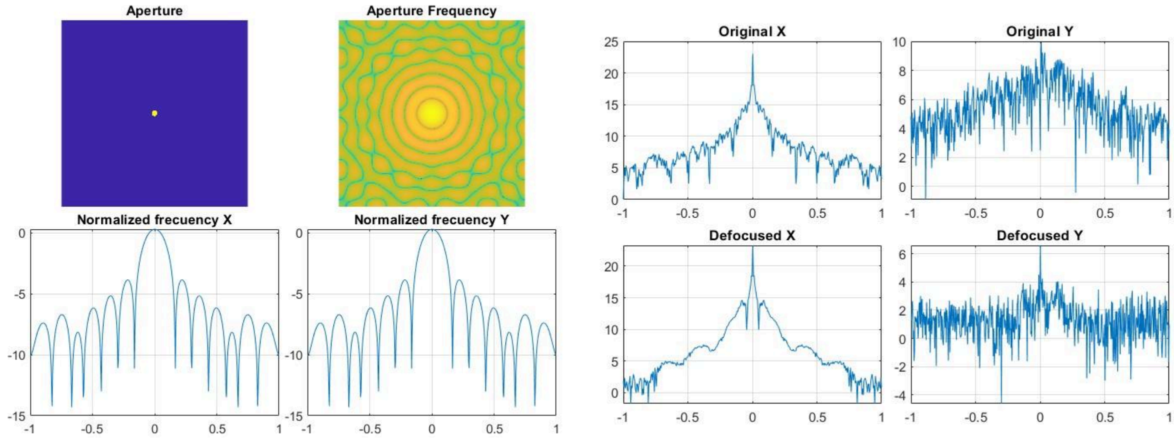


Figure 5: Circular aperture frequencies

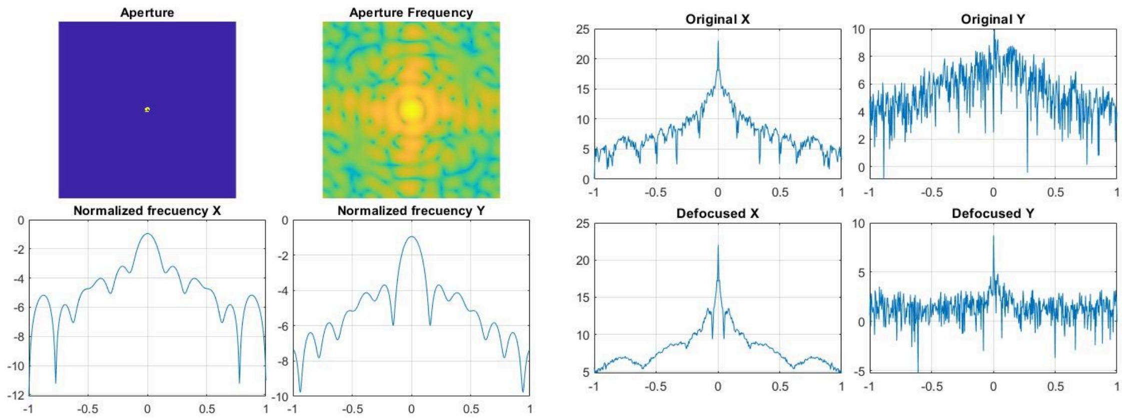


Figure 6: Zhou aperture frequencies

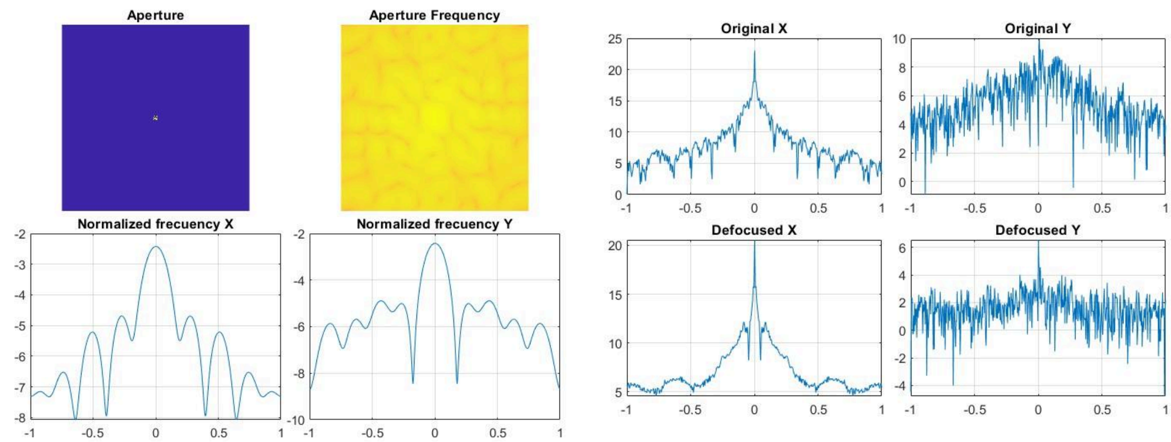


Figure 7: Raskar aperture frequencies

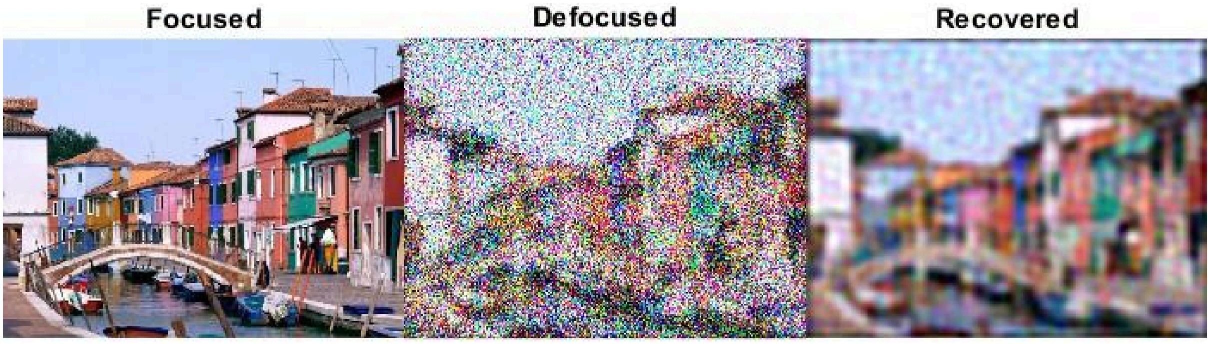


Figure 8: Colored image example