Project 1 : Image Enhancement

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1 Introduction

The goal of this project is to investigate the spatial and frequency domain image enhancement techniques such that the result of the process is more suitable. The image "Lena" will be used in order to compare the performance of the different processing operations.

2 Spatial domain processing

In this section, we will directly manipulate the picture elements of the image for contrast enhancement and denoising.

2.1 Histogram equalization

One technique for contrast enhancement is the histogram equalization. First, we simulate a low contrasted image by concentrating the grey-level of the image around one particular value. Then we apply the histogram equalization process.

We can see is from FIG.1 that the histogram is not flat. It is because we deal with a quantized image. That means the histogram is not a continuous function, and the equalization function consists only on shifting one grey-level to another. As a result, we have the same amounts of grey-levels but spread in order to exploit all the range [0, 255] (as the grey-levels are coded over 8 bits).

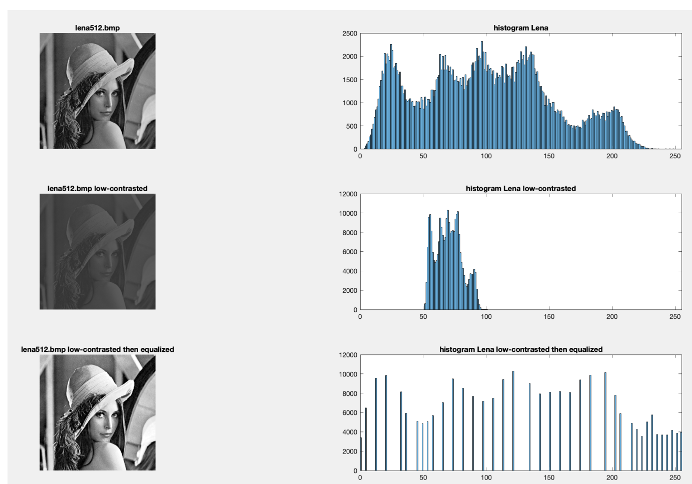

Figure 1 – Results contrast enhancement

2.2 Image denoising

The histogram of an image does not explicitly provide details regarding the noise in the image, thus manipulating the histogram is not effective for denoising. Another process to enhance a noisy image is the use of filters.

In this part, we will try to denoise images with filters in the spatial domain. We will focus on two kinds of noises : the Gaussian noise and the salt & pepper noise. FIG.2 2 shows the noisy images and their respective histogram plots.

We will study the performance of the mean filter and the median filter on the noises mentioned above.

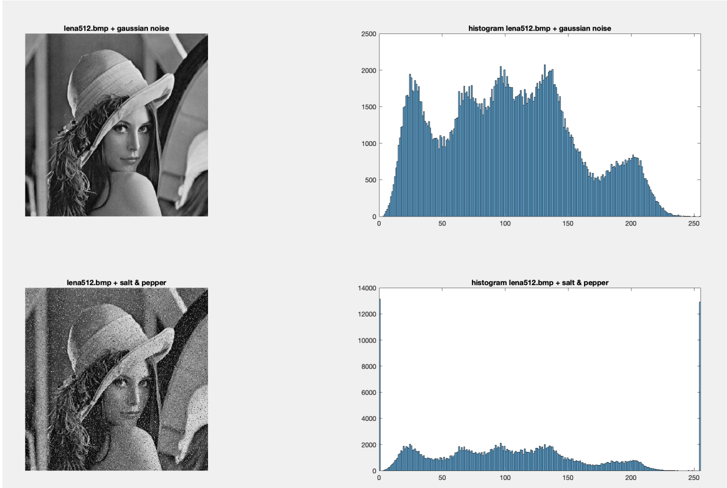

FIGURE 2 – Simulated noise

The difference between the mean filter and the median filter is that :

- the mean filter is a sliding-window spatial filter that replaces the center value in the window with the average of all the picture elements in the window.
- the median filter is also a sliding-window spatial filter, but it replaces the center value in the window with the median of all the picture element values in the window.

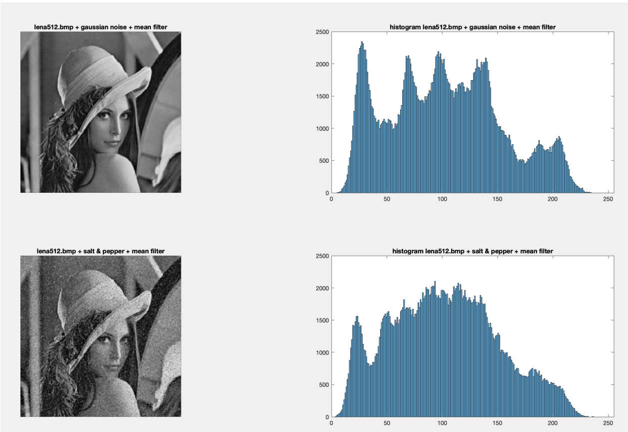

FIGURE 3 – Results with a mean filter

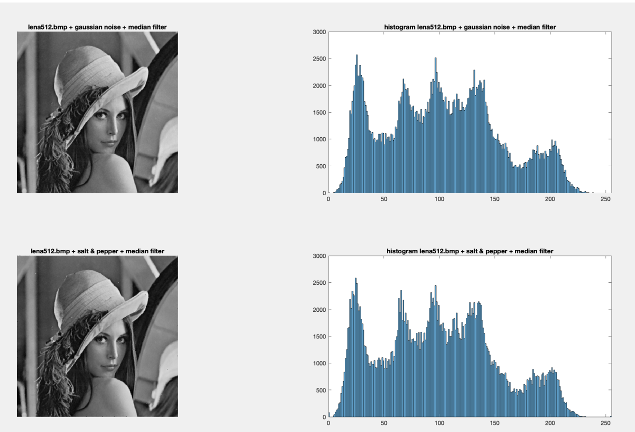

FIGURE 4 – Results with a median filter

If we look at the results in FIG.3 and FIG.4, we can see that the mean filter is efficient for a Gaussian noise. As a salt & pepper noise is composed by only 2 bits (black and white), the median filter eliminate those bits by taking the median value in the window. We can conclude that the use of a certain filter should correspond to a certain noise.

3 Frequency domain filtering

In this section, we will apply filters in the frequency domain. That means that we will enhance a noisy image by manipulating the Fourier Transform of the image.

We will focus on a blur noise and the goal of this section is the restore an out-of-focus image.

Frequency domain filtering is particularly interesting for sharpening application. Since convolution corresponds to multiplication in the frequency domain (convolution theorem), the use of the Wiener algorithm or the constrained least squares algorithm is practical.

FIG.5 shows the original image, Gaussian blurred image and corresponding magnitude of their frequency spectrum. It can be observed that the blurring effect has increased the concentration of the low frequency while attenuating the high frequency (like a low-pass filter).

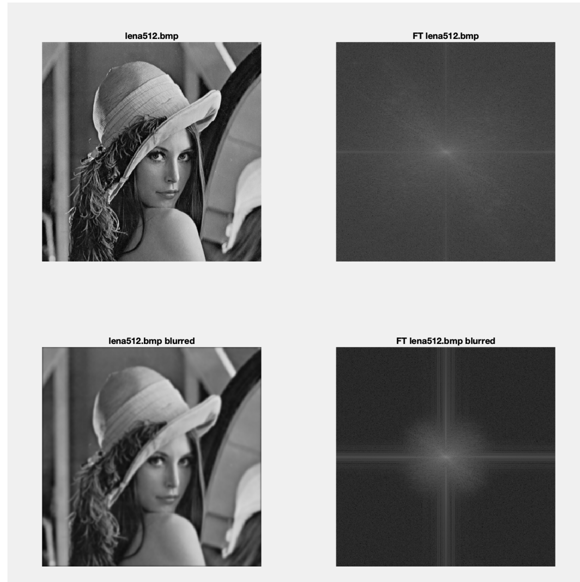

FIGURE 5 – Images and their Fourier Transform

Constrained least square algorithm is employed in order to sharpen the image with a gamma value that respects the constraint. FIG.6 and FIG.7 show the results before and after the application of the sharpening algorithm.

We chose to use the constrained least square (CLS) algorithm because this algorithm is less restrictive than the Wiener algorithm and determine the right parameter γ without doing trials and errors. However, we have implemented the Wiener filter in order to analyze the performance of the filters. From FIG.6, we cannot see any differences between the two restored images, thus the use of the Wiener algorithm over the CLS algorithm is not justified.

If we write the input image as $\mathbf{g} = H\mathbf{f} + \eta$, the estimate image in the frequency domain is

$$\hat{F}(u,v) = \frac{H^*(u,v)G(u,v)}{|H(u,v)|^2 + \gamma |P(u,v)|^2} \text{ with } P(u,v) = F[p(x,y)] \text{ and p(x, y)} = \begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix}$$

The constraint is $\parallel r \parallel^2 = \parallel \eta \parallel^2 \pm a$, where $r = g - H\hat{f}$.

FIGURE 6 – Results on blurred images (CLS : $\gamma = 1e^{-6}$, Wiener : $K = 1.5e^{-4}$)

FIGURE 7 – Results "on out of focus" images with CLS algorithm ($\gamma = 1e^{-5}$)

To avoid the issues with sharp edges on the boundaries of an image that provokes ringing in the restored image (because of the high-frequency drop-off when we calculate the DFT), we can periodize or mirror the image on every direction or tapered the edges with a window to smooth the edges. In our case, we smooth the edges by windowing the image with a Gaussian function.

We can see from FIG.6 and FIG.7 that the images are sharpened but they are not perfect. The outputs of the algorithm could be improved by adjusting the constraint (i.e improving the precision a on the constraint) or by doing some post-processing (we can applying a mean filter to eliminate the residual noise).

4 Conclusion

We observed various techniques in spatial filtering and frequency domain processing to remove the effect of several common noises. Several enhancement techniques were compared for different scenarios and conclusions were made. Finally, the sharpening algorithm was developed and the results were found to be useful.

5 References

[1] R. C. Gonzales and R.E. Woods, Digital Image Processing, Prentice Hall, Upper Saddle River, New Jersey, third edition, 2008.