Programming Assignment 2: Image denoising

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1 Introduction

The main purpose of this section is to create a bilateral filter. It should have certain weight depending in two basic features. The first feature will be the distance from the central pixel (the one to study) and the neighbours that are being considering. The second feature will be related with the difference in the intensity level between this pixel and its neighbours.

2 Fundamentals

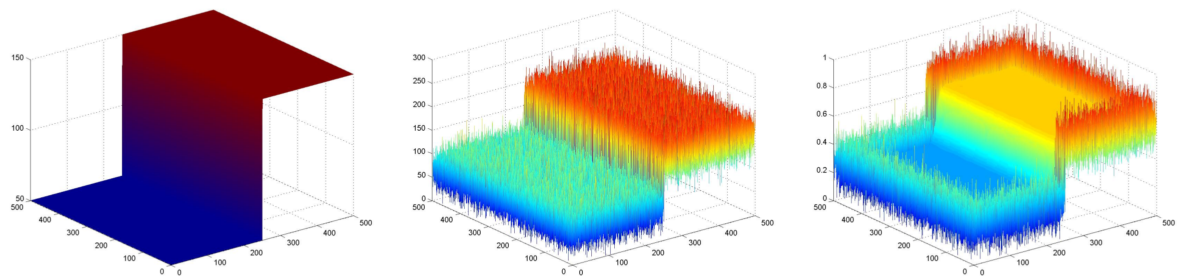
Let's imagine an original image to be filtered with a bilateral filter

$$I_0(x,y) = I(x,y) \tag{1}$$

$$I_{n+1}(x,y) = \sum_{i=-N}^{N}\sum_{j=-N}^{N} w_{ij} I_n(x,y) / \sum_{i=-N}^{N}\sum_{j=-N}^{N} w_{ij} \tag{2}$$

$$w_{ij} = exp\left(-\frac{dist^2(X_0, X_{ij})}{2*\sigma_d^2} - \frac{\left|I(X_0) - I(X_{ij})\right|^2}{2*\sigma_r^2} \right) \tag{3}$$

In this filter N is the length of half of the size of a square patch that will be consider as the neighbourhood of the pixel to study, and it is proportionally related to σ_d. Several differences from the previous lab could be observed, the size of the neighbourhood won't be fixed, and the border to apply padding neither. The weight is depending in two exponential functions, allowing to consider with the most important influence the closer pixel and the intensity of such pixels. The last parameter will be the number of iterations, in the case, n.



(a) Original (b) Noisy (c) Filtered

Figure 1: Synthetic image filtered with bilateral filter

3 Evaluation and analysis

Once that the effect of the filter was checked over a synthetic image, would be nice to check how it works over a real image.

Figure 2: Bilateral filter with $\sigma_d = 8, \sigma_r = 10, iterations = 1$

As it can be seen, the noise have been removed and edges are still remaining. It is also significant the size of the border, that of course, it not filtered. This padding problem could be partially solve mirroring the frame before applying the filter and cropping later on.

3.1 Analysis of σ_r variation

As the value of the parameter σ_r is increased the filter will tend to be a regular average filter. This will be done by averaging with the same weight the neighbours that belong to the patch that contain as the central pixel the one that is being analysed. So the evolution of the blurring over the image could be seen in Fig.3 as this parameter changes.

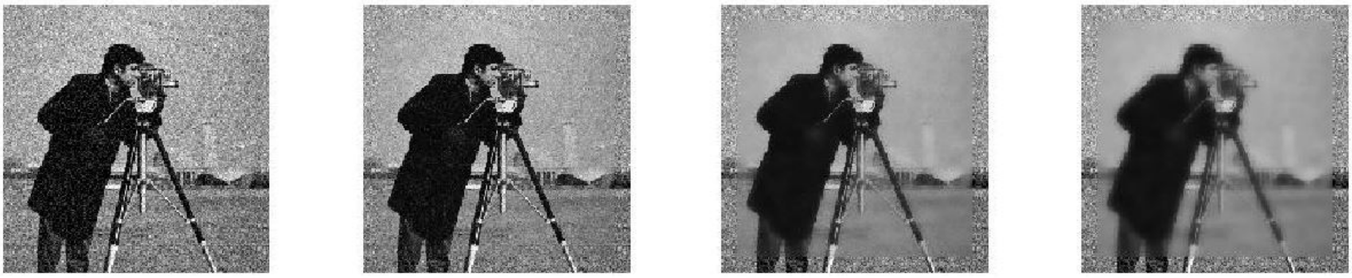


Figure 3: Bilateral filter with $\sigma_d = 75; \sigma_r = 4, 10, 20; iterations = 1$

3.2 Analysis of σ_d variation

The effect of increasing the parameter related with the distances will affect in a similar way to the filter. It should be remarked that the bigger this value is the more will affect to the borders of the image. This is shown in Fig.4. Adjusting these two first parameter would be possible to give more weight to the distances or to the intensities.

Figure 4: Bilateral filter with $\sigma_d = 25, 75, 125; \sigma_r = 4; iterations = 1$

3.3 Analysis of variation in the number of iterations

One of the advantages of this filter is that works pretty will even with just one iteration. The computational time will increase drastically as we the number of iterations rise.

Figure 5: Bilateral filter with $\sigma_d = 75; \sigma_r = 4; iterations = 1, 10, 20$

3.4 Comparison of bilateral filter with non-local means filter

Non-local means considers that each pixel x will have as neighbours any pixel y which neighbourhood is similar to the neighbourhood of x.

$$I(x) = \frac{1}{C(x)} \int_{\omega} e^{-\frac{1}{h^2} \int_{\Re^2} G_a(t)|u(x+t)-u(y-t)|^2 dt} u(y)dy \tag{4}$$

where G_a is a Gaussian kernel of standard deviation a and h as a filtering parameter.

Figure 6: Original noisy image. Bilateral filter with $\sigma_d = 50; \sigma_r = 4; iterations = 1$. NLMeans with $N = 9$

In Fig.6 a simpler version of the non-local means filter is used to compare with bilateral one. In a first instance is easy to check that the bilateral filter works much better in the preservation of the details (edges). The noise is also being removed in the non-local means filter. In the following pictures a deeper analysis will be performed.

Figure 7: Original noisy image. Bilateral filter with $\sigma_d = 50; \sigma_r = 4; iterations = 1$. NLMeans with $N = 9$

In this case a faster implementation of the non-local means has been used. In this case the edges are still better acquired by the bilateral filter but, non-local means seams to get more accurate grey levels.

Let analyse, Fig.8 the subtraction of the filtered images in both cases to the noisy image.

Figure 8: Original noisy. Noise after bilateral filter; Noise after non-local means filter

The information about the edges has been lost much more in the bilateral filter. The only area that has better results is the camera, where are very small lines in different directions limiting zones with relatively high contrast. This noise should be almost similar if the parameters are properly set up. Summing up, it could be said that these filters are much better than regular averaging or Gaussian ones for denoising purposes. The edges information remain in the filtered image and most of the noise has been removed.

References

[1] 'Advanced Image Analysis Notes', Alexander Belyaev, Heriot Watt University, 2014