Assignment 1: Image Filtering and Processing

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Introduction:

This assignment focuses on the development of our own personal image filtering processes using OpenCV, Matplotlib, and NumPy. We were expected to learn about how different filters affect our images in different states of noise and color. After getting comfortable with a few of the more common filters, we were then expected to produce high frequency noise with a technique of our choice, and then attempt to remove said noise. Our results were expected to be clearly plotted, labeled, and analyzed.

Implementation:

The filters that we used are listed as follows:

Smoothing Filters:

- Mean Filter (Smooth Blur with a 3x3 kernel)
- Gaussian Filter (with sigma = 1.0)
- Non-Local Means Denoising (In a personal attempt to add more noise reduction in q3)

Sharpening Filters:

- Laplacian Filter
- Unsharp Masking

Edge Detection Filters:

- Sobel filters (in both x and y directions)

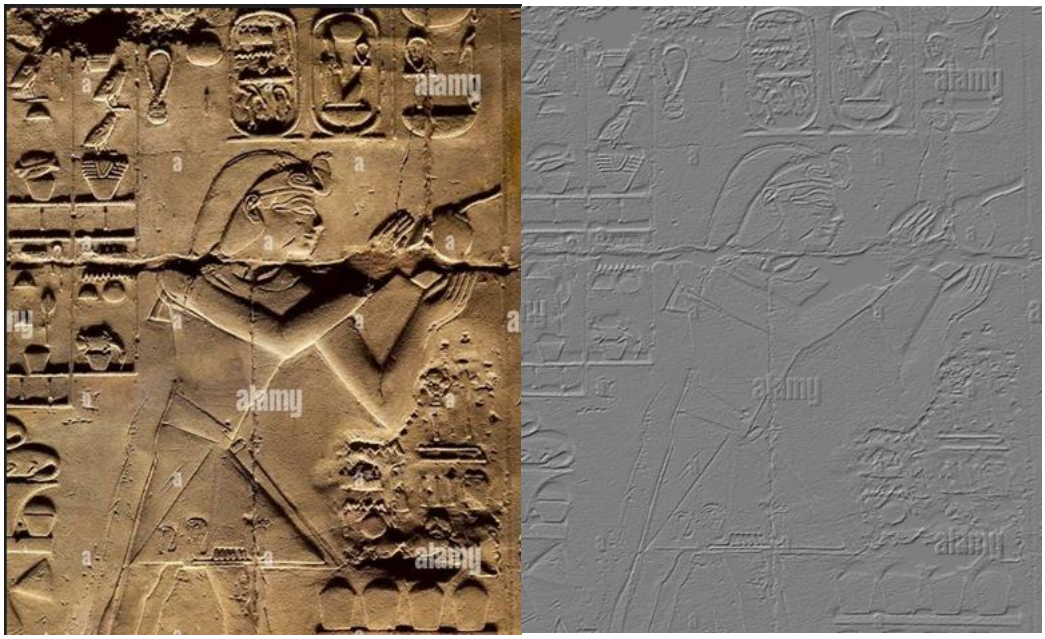
Results:

For questions 1 & 2, This is a display of the original image with the applied filter to the right.

If I were to go back and conduct this portion again, I might try to find a way to turn down the intensity of the Laplacian image sharpen just so I could see what's going on a little bit better.

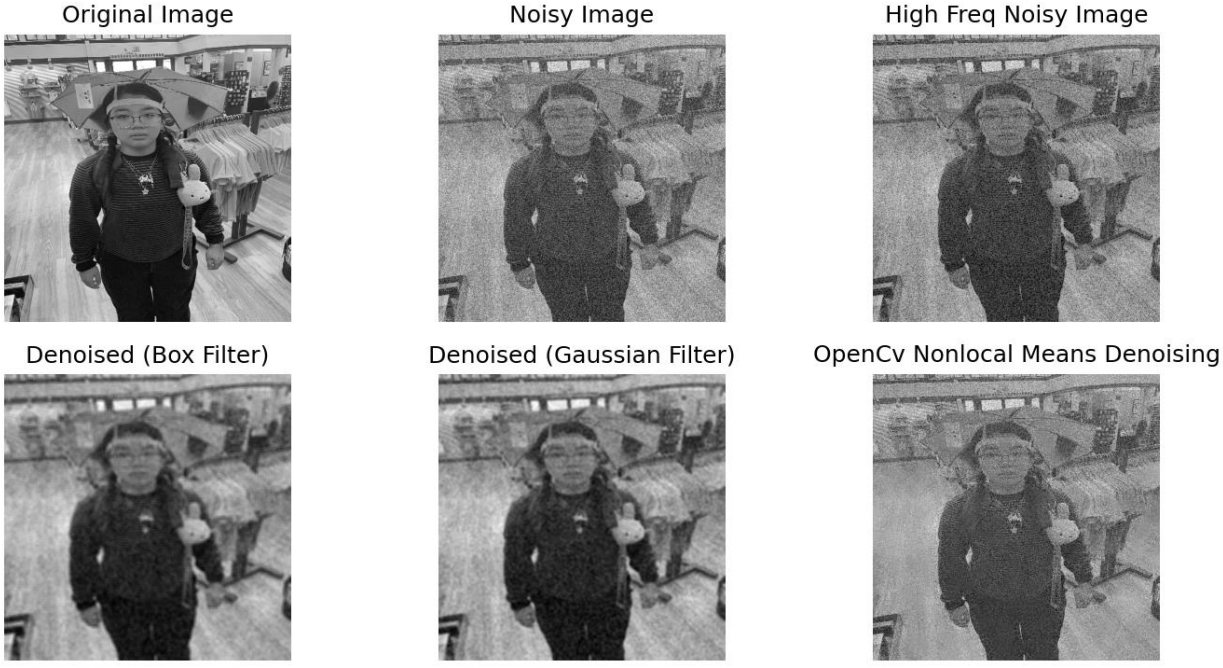
The Unsharp, Gaussian, and Mean (Smooth Blur) filters seemed to produce a similarly blurred and smoothed image. The unsharp masking filter did sharped and accentuate some of the higher intensity colors in the original image, such as the darker clothes and such. When it comes to Laplacian, the second derivative operator filter, the OpenCV documentation claims that it calls a Sobel operator to perform its operation. Laplacian and Sobel filters are good for determining edge detection in an image. As you can see in the Sobel filter (x & y directions), the edges of the image are clearly displayed. I was curious as to what the image would produce when both Sobel filters were added together, and this was the result:

Super cool! Every edge is clearly outlined here. I was thinking that this could be a really useful technique to analyze hieroglyphics for example as it clearly outlines each edge.



Take these two images for example. A lot of the cracking and contour is removed when both Sobel filters are applied, leaving only the more important hieroglyphs for analysis. Of course, the parameters could be tweaked and whatnot, but I feel that this technique could be very promising.

When it comes to image denoising, this is what I managed to come up with:



I’m not the happiest with my denoising technique as it seems I wasn’t able to get the high frequency noise to be different from the normal noisy image. I think I’d like to play around with it a bit more using convolution in a 2D space and whatnot.

The Box filter and Gaussian filter again gave me a similar result, with the gaussian filter appearing a little less blurred in the result whilst also producing a slightly less noisy image. The Nonlocal Means filter fell a little flat in my opinion even though it appears to be a fan favorite for image denoising. I wonder if my image had something to do with why some of the denoising techniques didn’t work as well as I had hoped they would.

Discussion:

Box Filter (Mean Filter)

- **Advantages**:
    1. Simple and computationally inexpensive.
    2. Effective in reducing random noise in an image by averaging the pixel values over a kernel, thus smoothing out variations.
    3. Works well for reducing high-frequency noise while retaining some level of detail.
- **Limitations**:
    1. Can introduce a significant blur, leading to a loss of sharpness and finer details.
    2. Does not perform well for edge preservation, as edges are often blurred together with noise.

2. Gaussian Filter

- **Advantages**:
    1. Provides better smoothing than the Box Filter due to its weighting mechanism (pixels near the center of the kernel have more influence).
    2. Reduces noise while maintaining some image details, especially around edges.
    3. Well-suited for image pre-processing tasks like noise reduction prior to applying edge detection algorithms.
- **Limitations**:
    1. Still introduces some blurring, particularly for high-frequency details like fine textures.
    2. Not as effective in preserving strong edges when compared to more advanced edge-preserving filters.

3. Laplacian Filter (High Pass Filter)

- **Advantages**:
    1. Excellent for edge detection by highlighting regions of rapid intensity change (high-frequency content).

2. Useful for enhancing image features like edges and textures, making it valuable in applications for object recognition.

- **Limitations**:
  1. Amplifies noise along with edges, making noisy images more difficult to process without additional denoising techniques.
  2. Not effective as a standalone filter for tasks that require smoothing or noise reduction.

4. Non-Local Means Denoising

- **Advantages**:
  1. A more advanced denoising algorithm that performs well on images with complex patterns, as it compares pixel patches across the image, not just locally.
  2. Can preserve edges better than simple smoothing filters like Gaussian or Box filters.
- **Limitations**:
  1. Computationally expensive and can be slower than other denoising techniques.
  2. May not be as effective when applied to images with high levels of high-frequency noise.

5. Sobel Filters (Edge Detection)

- **Advantages**:
  1. Simple and efficient for detecting edges in both horizontal and vertical directions.
  2. Can be combined to provide a comprehensive edge map of an image.
- **Limitations**:
  1. Like other high-pass filters, Sobel amplifies noise and might require smoothing to produce optimal results.

Conclusion:

All in all, I feel that I learned a great deal about image filtering and processing, setting me up for more advanced techniques in the future. The applications of some of the filters that we have explored feel almost endless and seem to have applications that could greatly benefit humankind. This assignment helped ingrain the importance of what filters to use when and where. I also learned the importance of tweaking parameters, as some filters require very specific parameters to work as intended, where others provide a wide range of possible outputs. Additionally, different filters can be stacked on top of each other to develop a certain image result and fill in for missed areas from one filter to another.