COL 783: Assignment 2
Denoising and Deblurring

Due date: Tuesday, ~~17~~ 24 September 2019

OVERVIEW

In class we have discussed many techniques for restoring images that have been degraded by noise and/or blur, from the "classical" averaging filters and Wiener filtering to more recent methods. In this assignment you will experiment with these techniques on some images with synthetic and real degradations.

REQUIREMENTS

Here are some test images you can use for your results: barbara, boat, sandiego, shepplogan. You may use built-in library routines for convolution, median filtering, and the Fourier transform.

Basic denoising

Add Gaussian noise to each test image to create a noticeably noisy image. Then explore the use of mean filters and median filters to reduce the noise: for each type of filter, try different filter sizes, compute the PSNR, and choose the filter size manually (or by some loop) to approximately maximize the PSNR. Then, do the same with salt-and-pepper noise instead of Gaussian noise. Report your observations, including the noisy and maximum-PSNR images and their corresponding PSNRs, and discuss what you can conclude about the effectiveness of the two filters in different cases.

Edge-preserving smoothing

Implement one of the edge-preserving smoothing methods discussed in class:

- Anisotropic diffusion (Perona and Malik, 1990)
- Total variation denoising (Rudin et al., 1992)
- Bilateral filtering (see the survey by Paris et al. 2009), only if you did not already implement it in Assignment 1
- Non-local means (Buades et al. 2005)

Demonstrate results on the same noisy images from the previous part.

Deblurring

Blur the clean image with a disk-shaped point spread function $h(x, y)$ and add some Gaussian noise. Compute the frequency-domain transfer function $H(u, v)$ of the PSF using an FFT. Calculate by hand the noise spectrum $|N(u, v)|$ using the orthogonality property ($\sum |N(u, v)|^2 \propto \sum |\eta(x, y)|^2$) and the known variance σ_η^2 of the added noise, and verify that it agrees with the computed FFT of the noise alone.

Then perform deblurring using the Wiener filter. For this, you will need to provide an estimate of the desired image's spectrum $|F(u, v)|$. Experiment with different choices: (i) use the ground-truth spectrum from the original image; (ii) use $|F(u, v)| = $ const; (iii) use $|F(u, v)| \propto (\sqrt{u^2 + v^2})^\alpha$ for some manually chosen α that best fits the ground-truth spectrum.

Real-world image restoration

We will soon provide some real-world images suffering from an unknown noise and blur. Your task will be to estimate the noise distribution and the point spread function purely from the given image, and then perform deblurring to recover a clean, sharp image as well as you can.

Extra credit

How can the edge-preserving property of modern denoising methods be incorporated in a deblurring method? One way is to replace the Laplacian criterion used in constrained least-squares filtering with one that penalizes noise but not sharp edges, such as the total variation (TV). This TV-regularized deconvolution approach results in a nonsmooth optimization problem, which can nonetheless be solved effectively with an appropriate algorithm such as ADMM. See Gordon Wetzstein's slides and notes for more details.

Implement this or any other technique you can find for edge-preserving deblurring, and show the results on some challenging examples.

SUBMISSION AND EVALUATION

Make sure your code works on the General Computing Lab machines, which have Python2+OpenCV and Matlab installed. If you are programming in a compiled language, include a Makefile or script which compiles the code without user input. In any case, your code should make it easy to run any of the different tasks on any user-provided image.

Along with your code, submit a report describing your work and any relevant mathematical derivations (e.g. calculating $|N(u, v)|$ from σ_η^2) and implementation choices (e.g. estimating $|F(u, v)|$). Explain how you estimated the noise and point spread function in the real-world restoration task. Include images demonstrating the results of each task of the assignment. You will be graded on both your working code and the comprehensiveness of the report.