E9 222 Signal Processing in Practice

Image Denoising (Due Feb 16, 2026)

1 Experiment 1 - Low pass Gaussian filter

Images corrupted with Gaussian noise are often denoised using a simple Gaussian low pass filter. If the noisy image is $y(m,n)$ and the desired denoised image is $\hat{x}(m,n)$, the denoised image is obtained as

$$\hat{x}(m,n) = \sum_{k=-P}^{P} \sum_{l=-P}^{P} w(k,l) y(m+k, n+l), \text{ where}$$

$$w(k,l) = C \exp\left(-\frac{k^2+l^2}{2\sigma^2}\right) \text{ and } \sum_{k=-P}^{P} \sum_{l=-P}^{P} w(k,l) = 1.$$

Here P corresponds to the window size and σ is the standard deviation of the Gaussian filter.

1. For each of given noisy images (except img167.bmp), find the optimal Gaussian filter of size 11×11 with standard deviation from the set $\{0.1, 1, 2, 4, 8\}$ with the best mean squared error. To compute MSE, use img167.bmp as the reference image. Show the images denoised with the best Gaussian filter for each of the noisy images in a single figure along with the noisy images.
2. Plot a curve between the image index (sorted visually in terms of increasing noise levels) and the standard deviation of the optimal Gaussian filter. Comment on the curve.

2 Experiment 2 - Bilateral filter

The bilateral filter is defined as

$$g(m,n) = \frac{1}{C(m,n)} \sum_{k=-P}^{P} \sum_{l=-P}^{P} G(k,l) H(f(m,n) - f(k,l)) f(m+k, n+l),$$

where

$$H(x) = \exp\left(-\frac{x^2}{2\sigma_H^2}\right) \text{ and } x \text{ is the intensity difference,}$$

$$G(k,l) = \exp\left(-\frac{k^2+l^2}{2\sigma_G^2}\right)$$

$$C(m,n) = \sum_{k=-P}^{P} \sum_{l=-P}^{P} G(k,l) H(f(m,n) - f(k,l)).$$

Find a bilateral filter to denoise the image noisybook.png corrupted by the Gaussian noise and compare the results with a Gaussian filter that also does equally well visually. Choose the parameters of the bilateral filter to give a visually good result.