E9 222 Signal Processing in Practice
Assignment 5

February 11, 2026

Dwaipayan Haldar

---

1. Experiment 1 – Low Pass Gaussian Filter

(a) Optimal Gaussian filter for each noisy image

Ans: For each noisy image (except `img167.bmp`, used as the reference), a Gaussian filter of size 11×11 was applied with $\sigma \in \{0.1, 1, 2, 4, 8\}$. The optimal σ was selected as the one minimizing the MSE with respect to the reference image `img167.bmp`.

Image	**File**	**Best σ**	**MSE (before)**	**MSE (after)**
Image 1	img125.bmp	0.1	24.77	24.77
Image 2	img6.bmp	0.1	79.70	79.70
Image 3	img108.bmp	1	919.07	185.04
Image 4	img32.bmp	1	1638.51	248.24
Image 5	img137.bmp	8	15423.49	1651.68

Table 1: Optimal Gaussian filter parameters for each noisy image (sorted by increasing noise level). MSE is computed w.r.t. the reference image `img167.bmp`.

Figures 1–5 show the noisy images alongside their denoised versions using the best Gaussian filter.

Figure 1: Image 1 (`img125.bmp`): Very low noise. Best $\sigma = 0.1$ (near identity filter). The image is already close to the reference, so minimal smoothing is optimal.

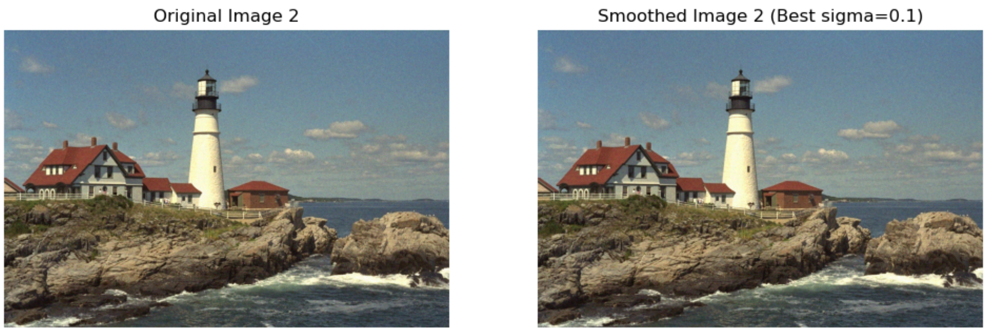

Figure 2: Image 2 (`img6.bmp`): Low noise. Best $\sigma = 0.1$. Slight noise present but still best handled with minimal filtering.

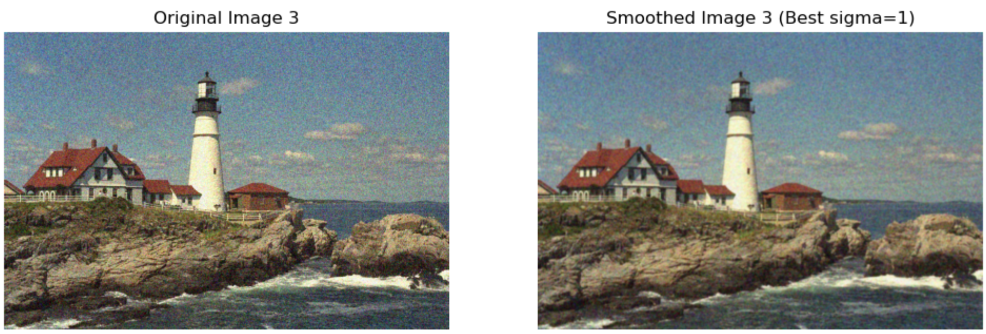

Figure 3: Image 3 (`img108.bmp`): Moderate noise. Best $\sigma = 1$. Visible noise requires moderate smoothing.

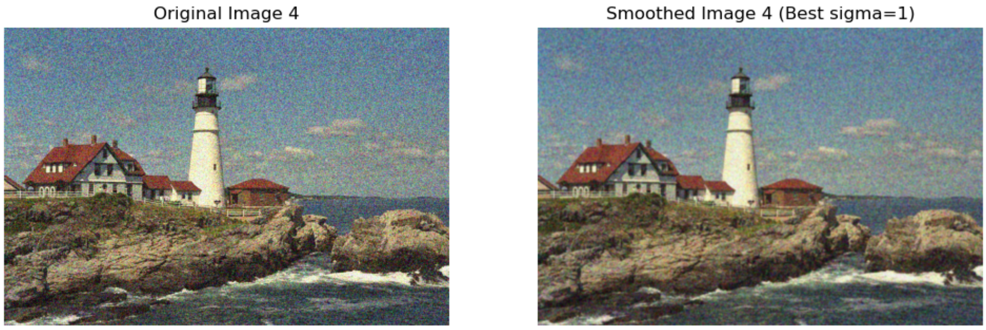

Figure 4: Image 4 (`img32.bmp`): Moderate–high noise. Best $\sigma = 1$. Heavier noise but the same σ as Image 3 is optimal.

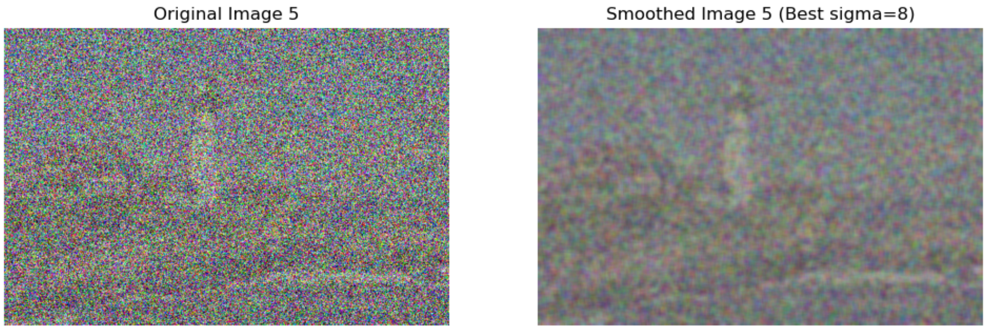

Figure 5: Image 5 (`img137.bmp`): Very high noise. Best $\sigma = 8$. The image is severely corrupted, requiring aggressive smoothing.

(b) Curve: Image index vs optimal σ

Ans: Figure 6 plots the optimal σ against the image index (sorted by increasing noise level).

Observations:

- The optimal σ increases monotonically with the noise level of the image. As the noise corruption becomes more severe, the Gaussian filter requires a larger standard deviation (wider spatial support) to suppress the noise effectively.
- For the least noisy images (Images 1 and 2), $\sigma = 0.1$ is optimal, meaning the filter acts nearly as an identity—preserving image details since there is little noise to remove.

- For the moderately noisy images (Images 3 and 4), $\sigma = 1$ provides the best trade-off between noise removal and detail preservation.
- For the most corrupted image (Image 5), $\sigma = 8$ is needed, resulting in heavy blurring. While this removes most noise, it also sacrifices fine image details—highlighting the fundamental limitation of Gaussian filtering, which cannot distinguish between noise and signal.
- The curve shows a generally increasing trend, confirming that **higher noise levels demand stronger (wider) Gaussian smoothing** for optimal MSE performance.

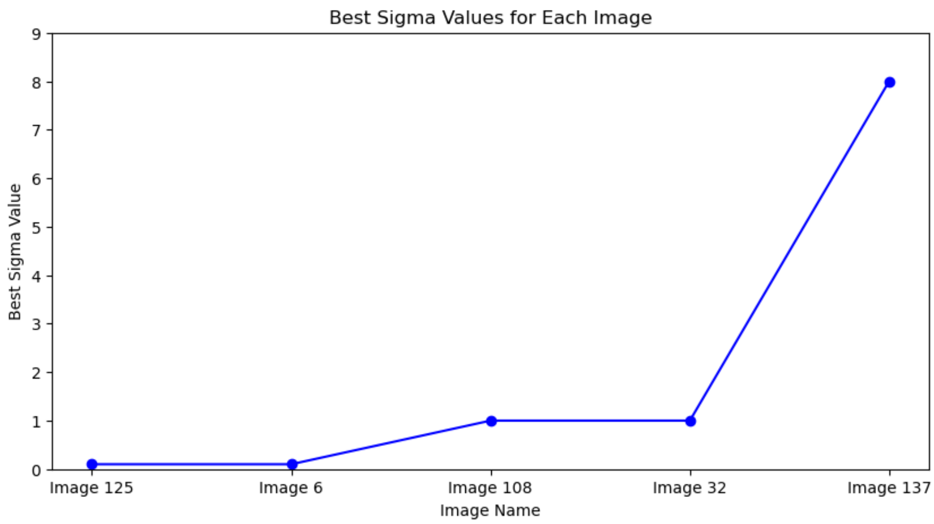

Figure 6: Optimal Gaussian σ vs image index (sorted by increasing noise level). The trend is monotonically increasing: noisier images require larger σ for best MSE.

2. Experiment 2 – Bilateral Filter

Ans: The bilateral filter was applied to `noisybook.png` with parameters: filter size $k = 11$, spatial $\sigma_s = 1.5$, and range $\sigma_I = 0.1$. A Gaussian filter with $k = 11, \sigma = 1.5$ (matching the bilateral filter's spatial parameter) was used for comparison. The Gaussian σ was varied and $\sigma = 1.5$ was selected as it gave a visually comparable level of denoising. Figure 7 shows the results.

Observations:

- Both filters successfully reduce the Gaussian noise present in the original noisy image.
- The **bilateral filter preserves edges significantly better** than the Gaussian filter. The text edges in the book cover ("Digital Image Processing") remain sharp and well-defined after bilateral filtering, whereas the Gaussian filter blurs them noticeably.

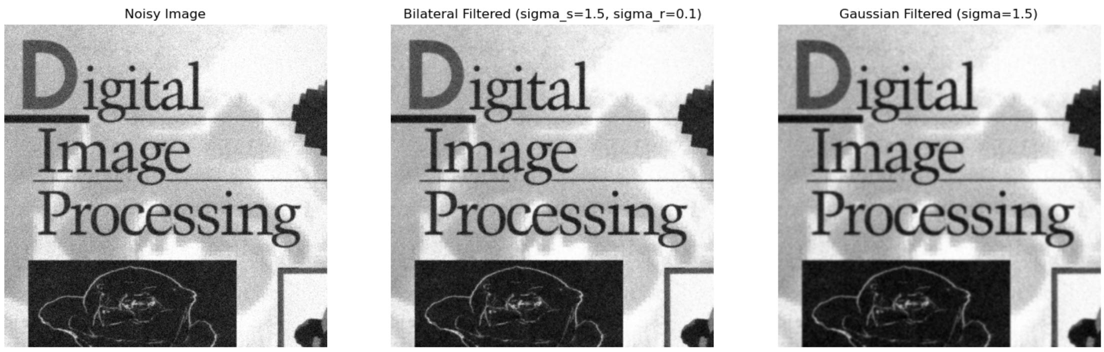

Figure 7: Comparison of bilateral and Gaussian filtering on `noisybook.png`. Left: noisy input. Center: bilateral filtered ($\sigma_s = 1.5$, $\sigma_r = 0.1$). Right: Gaussian filtered ($\sigma = 1.5$). The bilateral filter preserves text edges while the Gaussian filter blurs them.