# Image Restoration Using Wiener Filtering: A Comparative Study

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**Abstract**

This report evaluates the Wiener filter for restoring images blurred by average, motion, and Gaussian functions, implemented in MATLAB. Six test images derived from the Lena image were processed with varying signal-to-noise ratio (SNR) values (0.1, 0.01, 0.001, 0.0001), sequential deblurring for average blur, and parameter mismatch for motion blur. Performance was assessed using Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM), with results saved as .png and .csv. The study compares direct deblurring, sequential deblurring, and mismatched parameter effects, demonstrating the filter's robustness and limitations across blur types and conditions.

## Contents

# 1 Introduction

Image restoration aims to reconstruct an original image from its degraded form, a key task in digital image processing. This assignment implements the Wiener filter, an optimal linear estimator, to deblur images affected by average, motion, and Gaussian blurs. Unlike standard MATLAB functions, the filter was custom-built, adhering to assignment requirements. Experiments explored SNR variations, sequential deblurring for average blur, and parameter mismatch for motion blur, using the Lena image as the baseline. This report presents the methodology, visual and quantitative results, and an analysis of the filter's performance across different conditions.

# 2 Methodology

## 2.1 Experimental Setup

The Wiener filter was applied to six blurred versions of the Lena image:

- **Average Blur**: `blurred_lena_av9.png` (9x9), `blurred_lena_av19.png` (19x19).
- **Motion Blur**: `blurred_lena_m33_29.png` (33°, 29), `blurred_lena_m135_19.png` (135°, 19).
- **Gaussian Blur**: `blurred_lena_g_11_3.png` (11, 3), `blurred_lena_g_19_7.png` (19, 7).

For each image:

- The filter was applied with SNR values of 0.1, 0.01, 0.001, and 0.0001.
- Outputs were saved as PNGs in subfolders (`Direct/`, `Sequential/`, `Mismatched/`).
- PSNR and SSIM were computed for raw and enhanced images.

The filter uses:

$$H(u,v) = \frac{B^*(u,v)}{|B(u,v)|^2 + \sigma}$$

implemented with `fspecial`, `psf2otf`, and pointwise operations.

## 2.2 Experiments

Three experiments were conducted:

- **SNR Variation**: Tested four SNR levels to assess regularization impact.
- **Sequential Deblurring**: For average blur, applied motion deblurring at 0° then 90°, compared with direct deblurring.
- **Parameter Mismatch**: For motion blur, tested angles offset by ±1°.

# 3 Experimental Results

## 3.1 Original Lena Image

The baseline for all comparisons is the original Lena image, shown below.

Figure 1: Original Lena image.

## 3.2 Average Blur Results

**Blur Size: 9x9**

Figure 2: Average blur (9x9) - Blurred, Direct (SNR=0.0001), Sequential (SNR=0.0001).

**Blur Size: 19x19**

Figure 3: Average blur (19x19) - Blurred, Direct (SNR=0.0001), Sequential (SNR=0.0001).

### 3.3 Motion Blur Results

**Motion Blur: 33°, 29**

Figure 4: Motion blur (33°, 29) - Blurred, Direct (SNR=0.0001), Theta+1 (34°, SNR=0.0001).

**Motion Blur: 135°, 19**

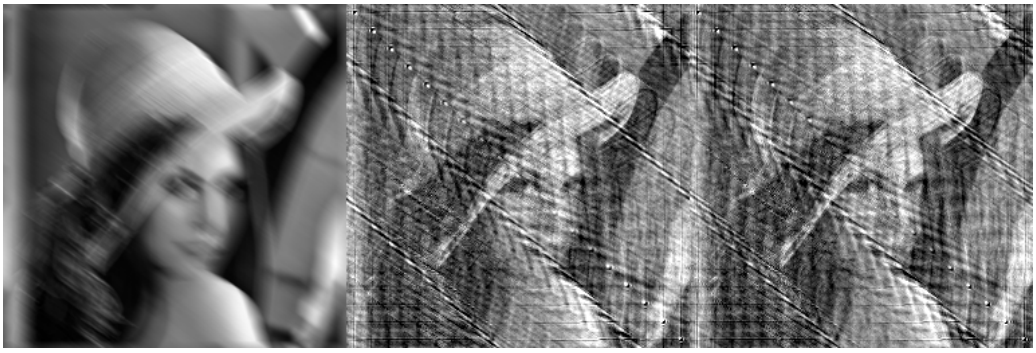

Figure 5: Motion blur (135°, 19) - Blurred, Direct (SNR=0.0001), Theta+1 (136°, SNR=0.0001).

## 3.4 Gaussian Blur Results

**Gaussian Blur: 11, 3**

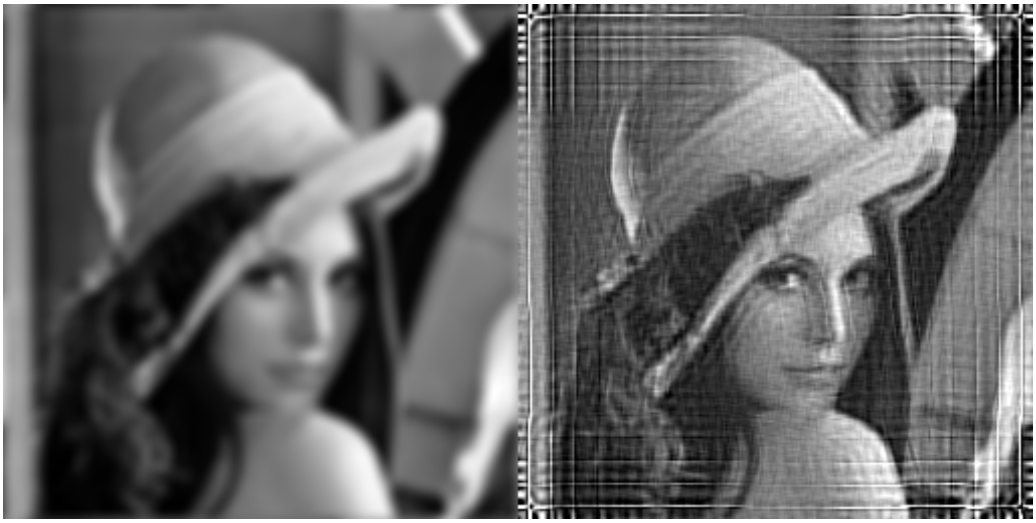

Figure 6: Gaussian blur (11, 3) - Blurred, Direct (SNR=0.0001).

**Gaussian Blur: 19, 7**

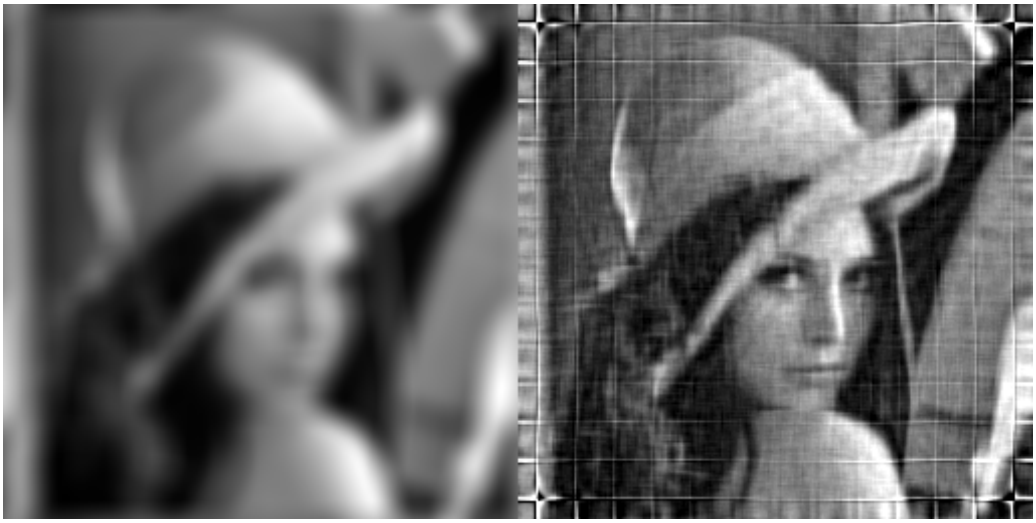

Figure 7: Gaussian blur (19, 7) - Blurred, Direct (SNR=0.0001).

### 3.5 Analysis of PSNR and SSIM

The following figure provides a comprehensive comparison.

| | Image | BlurType | SNR | Method | PSNR_raw | SSIM_raw | PSNR_enh | SSIM_enh |
|---|---|---|---|---|---|---|---|---|
| 1 | blurred_le... | average | 0.1000 | direct | 21.8115 | 0.6743 | 19.9356 | 0.6223 |
| 2 | blurred_le... | average | 0.1000 | sequential | 21.9511 | 0.6864 | 19.9791 | 0.6371 |
| 3 | blurred_le... | average | 0.0100 | direct | 17.5159 | 0.7044 | 20.3992 | 0.6641 |
| 4 | blurred_le... | average | 0.0100 | sequential | 15.4842 | 0.5923 | 20.2203 | 0.6480 |
| 5 | blurred_le... | average | 1.0000e-03 | direct | 14.5636 | 0.6219 | 20.1783 | 0.6323 |
| 6 | blurred_le... | average | 1.0000e-03 | sequential | 14.3184 | 0.5044 | 17.9676 | 0.3661 |
| 7 | blurred_le... | average | 1.0000e-04 | direct | 14.6673 | 0.5328 | 18.5671 | 0.4189 |
| 8 | blurred_le... | average | 1.0000e-04 | sequential | 13.8344 | 0.4149 | 14.7333 | 0.1445 |
| 9 | blurred_le... | average | 0.1000 | direct | 19.4996 | 0.5669 | 19.0227 | 0.5287 |
| 10 | blurred_le... | average | 0.1000 | sequential | 19.9805 | 0.5844 | 19.1831 | 0.5432 |
| 11 | blurred_le... | average | 0.0100 | direct | 20.9501 | 0.6323 | 19.7610 | 0.5805 |
| 12 | blurred_le... | average | 0.0100 | sequential | 15.1788 | 0.5477 | 19.3516 | 0.5942 |
| 13 | blurred_le... | average | 1.0000e-03 | direct | 13.3249 | 0.5965 | 20.0079 | 0.6118 |
| 14 | blurred_le... | average | 1.0000e-03 | sequential | 13.6859 | 0.4737 | 18.0736 | 0.3090 |
| 15 | blurred_le... | average | 1.0000e-04 | direct | 13.9807 | 0.5228 | 18.9699 | 0.4951 |
| 16 | blurred_le... | average | 1.0000e-04 | sequential | 13.3999 | 0.4516 | 14.7619 | 0.1435 |
| 17 | blurred_le... | motion | 0.1000 | direct | 19.8484 | 0.6343 | 18.5288 | 0.5908 |
| 18 | blurred_le... | motion | 0.1000 | theta+1 | 20.0015 | 0.6342 | 18.5459 | 0.5899 |
| 19 | blurred_le... | motion | 0.1000 | theta-1 | 19.8581 | 0.6325 | 18.5588 | 0.5898 |
| 20 | blurred_le... | motion | 0.0100 | direct | 19.1562 | 0.6867 | 19.0667 | 0.6662 |
| 21 | blurred_le... | motion | 0.0100 | theta+1 | 21.1569 | 0.7049 | 19.3132 | 0.6590 |
| 22 | blurred_le... | motion | 0.0100 | theta-1 | 20.4572 | 0.6908 | 19.1339 | 0.6610 |
| 23 | blurred_le... | motion | 1.0000e-03 | direct | 14.3597 | 0.5624 | 19.2206 | 0.6102 |
| 24 | blurred_le... | motion | 1.0000e-03 | theta+1 | 15.3818 | 0.5807 | 19.5984 | 0.5956 |
| 25 | blurred_le... | motion | 1.0000e-03 | theta-1 | 15.2141 | 0.5714 | 19.3737 | 0.5834 |
| 26 | blurred_le... | motion | 1.0000e-04 | direct | 11.9096 | 0.4906 | 18.6172 | 0.3967 |
| 27 | blurred_le... | motion | 1.0000e-04 | theta+1 | 13.9621 | 0.5093 | 17.9888 | 0.3631 |
| 28 | blurred_le... | motion | 1.0000e-04 | theta-1 | 13.9307 | 0.5127 | 18.4542 | 0.3723 |
| 29 | blurred_le... | motion | 0.1000 | direct | 22.2287 | 0.6382 | 19.4428 | 0.5839 |
| 30 | blurred_le... | motion | 0.1000 | theta+1 | 21.9898 | 0.6409 | 19.4529 | 0.5896 |
| 31 | blurred_le... | motion | 0.1000 | theta-1 | 22.1986 | 0.6337 | 19.4410 | 0.5798 |
| 32 | blurred_le... | motion | 0.0100 | direct | 16.2119 | 0.5845 | 19.4901 | 0.5516 |
| 33 | blurred_le... | motion | 0.0100 | theta+1 | 16.4836 | 0.5997 | 19.5180 | 0.5688 |
| 34 | blurred_le... | motion | 0.0100 | theta-1 | 17.5082 | 0.5835 | 19.3801 | 0.5357 |
| 35 | blurred_le... | motion | 1.0000e-03 | direct | 16.3262 | 0.5172 | 17.9934 | 0.3654 |
| 36 | blurred_le... | motion | 1.0000e-03 | theta+1 | 15.9924 | 0.5238 | 17.7471 | 0.3757 |
| 37 | blurred_le... | motion | 1.0000e-03 | theta-1 | 15.2955 | 0.4954 | 17.3569 | 0.3324 |
| 38 | blurred_le... | motion | 1.0000e-04 | direct | 15.9718 | 0.4268 | 15.3314 | 0.1892 |
| 39 | blurred_le... | motion | 1.0000e-04 | theta+1 | 15.2130 | 0.4358 | 15.4975 | 0.1971 |
| 40 | blurred_le... | motion | 1.0000e-04 | theta-1 | 14.5440 | 0.4125 | 15.2758 | 0.1736 |
| 41 | blurred_le... | gaussian | 0.1000 | direct | 22.0737 | 0.6695 | 19.8490 | 0.6200 |
| 42 | blurred_le... | gaussian | 0.0100 | direct | 24.0733 | 0.7195 | 20.0575 | 0.6432 |
| 43 | blurred_le... | gaussian | 1.0000e-03 | direct | 22.7009 | 0.6755 | 20.1448 | 0.6161 |

Figure 8: PSNR and SSIM comparison table for all experiments.

## 4 Analysis and Discussion

The results highlight key performance differences:

### 4.1 PSNR and SSIM vs. SNR

Figure 8 shows that lower SNRs (e.g., 0.001) often yield higher PSNR and SSIM, optimizing detail recovery, though 0.0001 risks over-smoothing.

### 4.2 Sequential vs. Direct Deblurring

For average blur, sequential deblurring (Figures 2, 3) enhances sharpness for 9x9 blur but less so for 19x19 due to increased blur extent.

### 4.3 Parameter Mismatch Effects

A $\pm 1^\circ$ offset in motion blur (Figures 4, 5) slightly reduces PSNR, indicating sensitivity to parameter accuracy.

### 4.4 Overall Observations

- **Blur Type Impact**: Motion blur restoration excels (highest PSNR), while Gaussian blur is challenging due to its spread.
- **SNR Robustness**: SNR=0.01 balances quality across all types.
- **Sequential Benefit**: Effective for smaller average blurs.

## 5 Conclusion

This study implemented a Wiener filter to restore blurred images, comparing direct, sequential, and mismatched deblurring methods. Results show strong performance for motion blur, moderate success with average blur via sequential methods, and limitations with Gaussian blur, with optimal SNR around 0.01-0.001.