1 Introduction

This report shows deblurring results, obtained from 3 different methods and evaluates them based on empirical quality of the resulting deblurred image, sensitivity of the added noise to the original blurred image, and the execution speed.

The methods used for deblurring in this report are: a) Wiener, b) Landweber, and c) Richardson-Lucy restoration schemes. Reviewed methods have certain parameters that should be set based on observations. Parameters for this report were selected based on the best results obtained from arbitrarily chosen values (K and number of iterations). Other values, such as the size of the filter kernel, amount of added noise, Gaussian sigma, motion blur settings, etc. were chosen randomly.

Every experiment had been conducted using certain deblurring method, testing performance on both Gaussian blur and motion blur for both weak and strong added noise parameters.

All the parameters were kept constant across experiments to ensure the same baseline to support comparison between results obtained by different deblurring methods.
2 Experiments

1. Wiener filter (Average processing time = 0.687s)

Blur: Gaussian, $\sigma=2$, filter box=$15 \times 15$; Added noise: $(1/N) \ast \text{randn(size(image))}$; $K=0.0000001$

Reconstructed above images

Blur: Circular motion, motion length=2 pixels, $\theta = 15^\circ$ CCW; Added noise: $(1/N) \ast \text{randn(size(image))}$

Reconstructed above images
2. Landweber method (Average processing time = 1.112s)

Blur: Gaussian, $\sigma=2$, filter box $= 15 \times 15$; Added noise: $(1/N) \ast \text{randn}(\text{size(image)})$; Iterations: 1000

Reconstructed above images

Blur: Circular motion, motion length $= 2$ pixels, angle($\theta$) $= 15^\circ$ CCW; Added noise: $(1/N) \ast \text{randn}(\text{size(image)})$; Iterations: 1000

Reconstructed above images
3. Richardson-Lucy (Average processing time = 0.967s)

Blur: Gaussian, $\sigma=2$, filter box=$15 \times 15$; Added noise: $(1/N) \ast \text{randn}(\text{size(image)})$

Reconstructed above images

Blur: Circular motion, motion length=2 pixels, angle($\theta$) = 15° CCW; Added noise: $(1/N) \ast \text{randn}(\text{size(image)})$

Reconstructed above images
3 Reconstruction Comparison

Presented reconstruction is compared using results obtained with

- Added noise of \( \frac{1}{5000} \times \text{randn(size(image))} \)
- 1000 iterations for Landweber method
- Circular motion blur with 2 pixels motion pixels and 15° angle(\( \theta \)) CCW
- Gaussian blur with \( \sigma=2 \) and 15 × 15 filter box
4 Discussion

The report shows deblurring results using different reconstruction schemes. From the results given in the Reconstruction Comparison Section it can be seen that, assuming medium added noise level, the reviewed schemes give different results.

For the reconstruction of the Gaussian-blurred image, the Richardson-Lucy scheme produces the best quality results that sharpen both background and foreground of the image for both high-intensity changes and low intensity changes. Wiener method sharpens Gaussian blurred image so that it resembles the original image. The disadvantage of the Wiener scheme is that it enhances added noise to the blurred image. The worst reconstruction quality is observed from the results obtained from using the Landweber method. The slight sharpening can be noticed, but the resulting image is not sharp enough (this may be due to the number of iterations).

In the case of the motion blurred image together with added noise, the best quality after the reconstruction can be observed on the results, obtained using the Wiener method. This is not expected, because the results obtained using the same method on Gaussian-blurred image produced reconstructed image with enhanced noise, which is almost not observed on the motion-blurred reconstructed image. Reconstructing motion-blurred image produces unwanted silhouette lines around objects with the most intensity changes. Nevertheless, Richardson-Lucy method gives sharper resulting image than the Landweber method, which may be due to the chosen number of iterations for the Landweber method.

Sensitivity to the added noise is noticeable in case of all the deblurring schemes. Although, while Wiener fails to reconstruct the image from string noise, both Landweber and Richardson-Lucy produce interpretable output. In Landweber case, the motion blur affects the reconstruction the most, while, in case of the Richardson-Lucy method, the reconstructed image is darkened.

Average computational speed varies across the different methods with Wiener scheme being the fastest, Landweber method (1000 iterations) is almost twice the speed of the Wiener method and is dependent on the number of iterations chosen. Richardson-Lucy has the medium processing speed, but produces empirically better results that the Landweber method with 1000 iterations for both Gaussian blur and motion blur with the added noise.
Appendices

Wiener Deblurring Matlab Implementation

```matlab
K=0.0000001;

f = im2double(imread('image_file_name.extension'));
h=fspecial('gaussian',15,2);
Blurred=imfilter(f,h,'circular');
noise = (1/10000)*randn(size(f)); %10000, 5000, 10

G = fft2(g);
H = psf2otf(h, size(g));
H2 = conj(H).*H;

F = (H./(H2+K)).*G;

fRestored = real(ifft2(F));

imshow(g);
imshow(fRestored);
```
f = im2double(imread('image_file_name.extension'));
h = fspecial('motion',15,2);
Blurred = imfilter(f,h,'circular');
noise = (1/10000)*randn(size(f)); %10000, 5000, 10
g = Blurred + noise;
G = fft2(g);
H = psf2otf(h,size(g));
H^2 = conj(H).*H;
F = zeros(size(f));
F_prev = zeros(size(f));

for iteration=1:1000
    F = F_prev + 0.1.*H^2.*(G - H.*F_prev);
    F_prev = F;
end

imshow(g);
F_restored = real(ifft2(F));
imshow(F_restored)
Richardson-Lucy Deblurring Matlab Implementation

```matlab
f = im2double(imread('image_file_name.extension'));

noise = (1/10000)*randn(size(f)); %10000, 5000, 10

h = fspecial('motion',15,2);
Blurred = imfilter(f,h,'circular');
g = Blurred + noise;
imshow(g)

imshow(deconvlucy(g,h,20));
```