Assignment 4
Mastering Basic Image Restoration Techniques

Please remember:

1. What you must hand in includes the assignment report (.pdf), source codes (.m) and output files (.png). Please insert each part in a different folder, and zip them all together into an archive file named according to the following template: HW4_XXXXXXXX.zip
   Where XXXXXXXX must be replaced with your student ID.
2. Your work will be evaluated mostly by the quality of your report. Don't forget to explain what you have done, and provide enough discussions which proves you have realized the subject.
3. 5 points of each homework belongs to compactness, expressiveness and neatness of your codes and report.
4. By default, we assume you implement your codes in MATLAB. If you're using Python, you have to use equivalent functions when it is asked to use specific MATLAB functions.
5. Your codes must be separated for each question, and for each part. For example, you have to create a separate .m file for part b. of question 3. Please name it like p3b.m.
6. "Keywords" will help you find useful information about the problem. They may also include some ideas for solving that problem.
7. Using built-in functions is not allowed, except for simple operations like reading, displaying, converting and saving images, or in cases it is clearly mentioned in "Allowed MATLAB Functions" section of each problem.
8. **Please upload your work in Moodle, before the end of June 8th.**
9. If there is ***any*** question, please don't hesitate to contact me through the following email address: **ali.the.special@gmail.com**
   I'd be glad to help.
10. Unfortunately, it is quite easy to detect copy-pasted or even structurally similar works, no matter being copied from another student or internet sources. Try to send me your own work, without being worried about the grade! ;)

1. Applying Spatial Filtering on a Binary Image (8 Pts.)

Keywords: *Spatial Filtering, Arithmetic Mean Filter, Geometric Mean Filter, Harmonic Mean Filter, Contraharmonic Mean Filter, Order-Statistics Filters, Midpoint Filter, Median Filter, Min Filter, Max Filter*

Spatial Filtering is a powerful mean to modify or enhance an image. As a neighborhood operation, it works by applying some algorithms to the values of the pixels in the neighborhood of any given pixel, to determine its value in the output image.

In this problem, you are to work with some basic spatial filters which work similar to most of the filters you are already familiar with. After understanding how a particular filter affects the image, please give a brief verbal description of the result.

You are working with the image "bars.png" as the input image. Please apply the following filters upon it.

a. Arithmetic mean filter with the size of 3×3, 7×7 and 9×9.
b. Geometric mean filter with the size of 3×3, 7×7 and 9×9.
c. Harmonic mean filter with the size of 3×3, 7×7 and 9×9.
d. Contraharmonic mean filter with the size of 3×3, 7×7 and 9×9, where Q = 1.5 and Q = -1.5.
e. Midpoint filter with the size of 3×3, 7×7 and 9×9.
f. Median filter with the size of 3×3, 7×7 and 9×9.
g. Min filter with the size of 3×3, 7×7 and 9×9.
h. Max filter with the size of 3×3, 7×7 and 9×9.

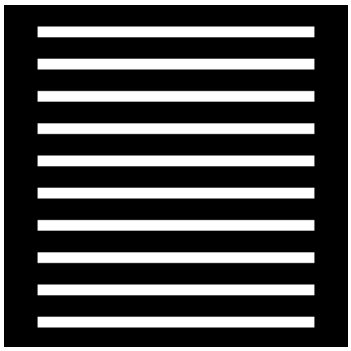

Figure 1 Input image of the problem 1. The white horizontal bars are 8 pixels wide and 250 pixels high, while the distance between them is 16 pixels

Note: This problem may seem a bit tedious. However, it is worth the effort, as it brings a real understanding of how these filters work.

Allowed MATLAB functions: `im2double()`, `rand()`, `random()`, `log()`,`exp()`, `find()`

2. Adding Different Types of Degradations to Images (8 Pts.)

Keywords: *Spatial Filtering, Gaussian Noise, Salt-and-Pepper Noise, Uniform Noise, Rayleigh Noise, Gamma Noise, Exponential Noise, Atmospheric Turbulence, Motion Blur*

Although the ultimate goal of **Image Restoration** is to achieve a better image quality, sometimes it is more desirable to add degradations to the images on purpose. It is mostly in the cases when a more natural and realistic image is preferred, or the objective is to build creative effects.

In this problem, you are going to use known models of degradation to degrade images. It would be beneficial to see the effects of each degradation and their parameters on an image.

Figure 2 The image of bald Trump, consisting only five different intensity levels

a. Implement a function to add Gaussian noise to an image. Your function should be able to specify the noise specific parameters. Apply it on the image "bald_trump.png" with three arbitrary settings, and display the results and compare histograms of clean and noisy images.
b. Repeat part a. for salt-and-pepper noise.
c. Repeat part a. for uniform noise.
d. Repeat part a. for Rayleigh noise.
e. Repeat part a. for gamma noise.
f. Repeat part a. for exponential noise.
g. Implement a function to add atmospheric turbulence to an image. Your function should be able to specify the parameter k, which determines the degree of turbulence. Apply it on the image "trump_tower.jpg" with three settings to produce "low", "mild" and "severe" atmospheric turbulence, and display the results.

Figure 3 A view of Trump Tower in Manhattan (black building in the centre), which is used for adding atmospheric turbulence

h. Implement a function to add motion blur to an image. Your function should be able to specify the parameters a and b, which determine the distance of the motion in each directions. Apply it on the image "trump_hair.jpg" with three arbitrary settings, and display the results.

Figure 4 Image of Trump's disheveled hair, which is used for adding motion blur

Note: The results in part g. and h. must be in RGB space.

Allowed MATLAB functions: `imhist()`, `exp()`, `fftshift()`, `fft2()`,`real()`, `meshgrid()`

3. Noise Reduction of Nasir al-Din Shah Qajar's Old Photos (8 Pts.)

Keywords: *Image Denoising, Spatial Filtering, Additive Noise, Gaussian Noise, Impulse (Salt-and-Pepper) Noise, Periodic Noise*

Spatial Filtering is widely used in image restoration, especially when the goal is to reduce noises of type additive. Choosing appropriate filter depends on many factors, including noise type, amount and distribution. The same goes for the parameters associated with it, like filter size or filter specific constants.

The goal of this problem is to demonstrate the usage of noise reduction techniques in image restoration, as well as testing your skills in finding the most convenient filters and filter settings for noise reduction purpose. Although the emphasis is on spatial denoising techniques, in some cases you may find frequency domain filtering useful as well.

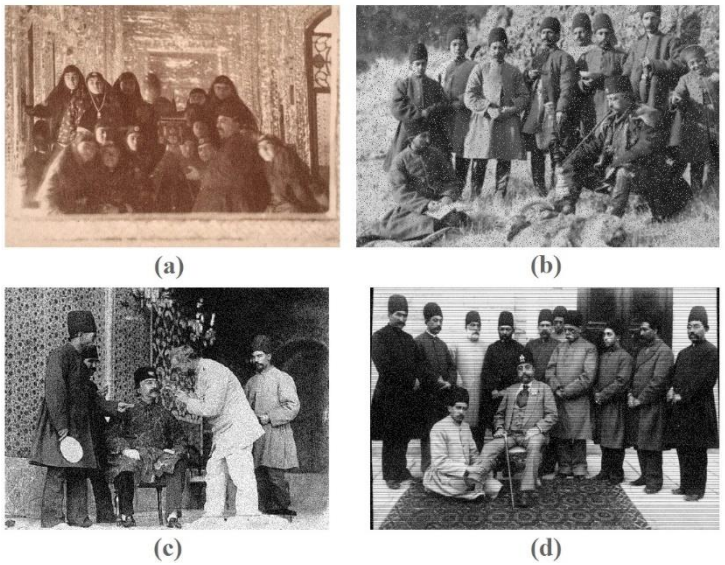

Figure 5 Different photos of Nasir al-Din Shah, corrupted with different types of noises (a) King taking mirror selfie with his wives (b) King smoking hookah after hunting a ram (c) King receiving dental treatment (d) King receiving a service known as "Pacheh-khaari"

a. Load the image "nasir_and_wives.jpg". Depending on the characteristics of the noise you observe, select an appropriate filter as well as suitable parameters to reduce the noise in the image. You are free to apply more than one filter as well.
b. Repeat part a. for the image "nasir_smoking_hookah.jpg".
c. Repeat part a. for the image "nasir_and_dentist.jpg".
d. Repeat part a. for the image "nasir_receiving_pachekhari.jpg".

Note: You may not be able to remove noises entirely, but your final result must be worth the effort.
Allowed MATLAB functions: `imfilter()`, `fspecial()`, `roifilt2()`, `imgaussfilt()`, `wiener2()`, `medfilt2()`, `ordfilt2()`, `imboxfilt()`, `fft2()`, `ifft2()`, `fftshift()`, `abs()`,`angle()`,`log()`,`im2double()`

4. Comparison of Different Methods for Resolution Enhancement (8 Pts.)

Keywords: *Image Interpolation, Image Super-Resolution, Nearest-Neighbor Interpolation, Bilinear Interpolation, Nearest Neighbor Value Interpolation, Non-uniform Interpolation*

Image Interpolation is an image processing method by which the number of pixels comprising an image is increased. **Nearest-Neighbor Interpolation** is the simplest way of image interpolation, where the values of an unknown pixel is determined by the value of its nearest pixel, while **Bilinear Interpolation** works by interpolating pixel intensity value using more pixel neighbors, based on their distances to the unknown pixel.

All image interpolation methods use only local pixel information, therefore they cannot add new details to the image. **Image Super-Resolution**, on the other hand, is a different class of image processing techniques which not only enhances image resolution, but also tries to add new information to the image.

The purpose of this problem is to practice enhancing image resolution using these methods. You are going to work with image "trump_washington-lr.jpg", as the input image.

Figure 6 Low-resolution input of part a. to part c.

a. Rescale the input image by the factor of 2 using nearest-neighbor interpolation method.
b. Rescale the input image by the factor of 2 using bilinear interpolation method.
c. Rescale the input image by the factor of 2 using nearest neighbor value interpolation. Note that in this method, the missing pixel value is estimated by the nearest value rather than the distance. In other words, the nearest neighbor value interpolation considers the four pixels directly surrounding the empty location, and selects the one whose value is almost equal to the value obtained by bilinear interpolation method.
   Useful Links: [1], [2]
d. (Additional point) You are provided with four low-resolution images (instead of one), each with a subpixel shift with respect to each other. Considering the given shift information and images names in Figure 7, rescale the input images by the factor of 2 using non-uniform interpolation.
   Note: Although this is considered as a super-resolution technique, the procedure is very similar to the prior interpolation methods.
e. Calculate and compare PSNR of part a. to part c. (or part d., if you have done it) results. You can use the given groundtruth image "trump_washington-gt.jpg". Also comment on visual appearance of the results.

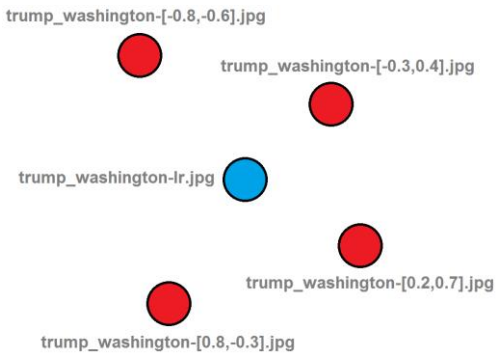

Figure 7 Pixel positions of the given low-resolution images for part d. (shown in red), with respect to the main low-resolution image pixel (shown in blue)

Allowed MATLAB functions: `size()`, `ceil()`, `meshgrid()`, `psnr()`

5. Getting More Familiar with Some of the Applications of Image Interpolation (12 Pts.)

Keywords: *Image Interpolation, Image Warping, Image Inpainting, Image Watermarking, Image Morphing*

In addition to resolution enhancement, **Image Interpolation** can also be used in various image processing applications. In this problem, you will get hands-on experience in some of them.

a. **Image Warping** is the process of manipulating a digital image so that different parts in the image have been significantly distorted. It may be used in many purposes; from correcting image distortion to creating funny images.
The goal of this part is to apply warping on the input image, "trump_shout.jpg". You are free to choose any warping pattern you like.

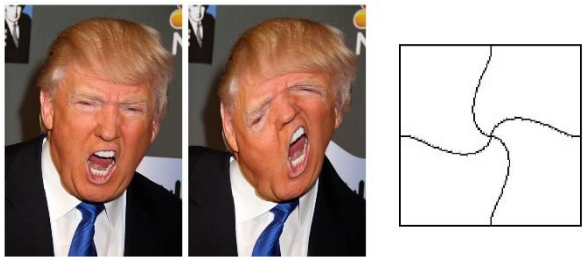

Figure 8 Input image alongside a warping example obtained by Photoshop using the given pattern

b. **Image Inpainting** is the usage of some image processing techniques to reconstruct lost or corrupted parts on an image. Load the image "queen_elizabeth_wedding.jpg", and try to replace the corrupted parts using neighborhood information.
Note: There are several fold effects in the input image, but you just have to remove the most prominent ones which can be seen as two horizontal (in the middle) and vertical (in the left) lines in the picture.

Figure 9 Photograph of Queen Elizabeth II in her wedding, with fold effects appear as two horizontal and vertical lines

Figure 10 An internet meme containing a note, which is desired to be removed

c. **Image Watermarking** is the process of embedding a type of marker in an image, typically to identify the owner or creator of the image. Your goal in this problem is to remove watermark (appears as image caption) from the image "harry_meghan.jpg".
Note: You just have to remove the caption inside the image. Your result might look unnatural.

d. **Image Morphing** is an image processing technique that changes one image into another through a sequence of intermediate images. It is mostly used to depict one person's image turning into another.
In this part, you are to do the same on two images "donald.png" and "mahmoud.png". Start with the image "donald.png" and display 10 intermediate images, before turning into the image "mahmoud.png".

Figure 11 From left to right; starting point, an intermediate state and the target image of the morphing process

Allowed MATLAB functions: `imtool()`, `imresize()`, `meshgrid()`, `interp2()`

6. Applying Notch Filters to Remove Periodic Patterns (15 Pts.)

Keywords: *Notch Filters, Periodic Noise*

Notch Filters are used to reduce the effect of periodic noise or repetitive patterns from an image. They do so by attenuating a selected frequency – and some of its neighbors – and leave other frequencies of the image Fourier transform unchanged.

In this problem, you will get familiar with notch filters and their capabilities in removing periodic patterns – including noises – from an image.

a. Load the image "curiosity_rover_selfie.png" and display the corresponding spectrum. As can be seen, the image suffers from a periodic noise. Use notch filters to remove it from the image, and display the result.
b. Repeat part a. with the image "curiosity_rover_exploration.png".

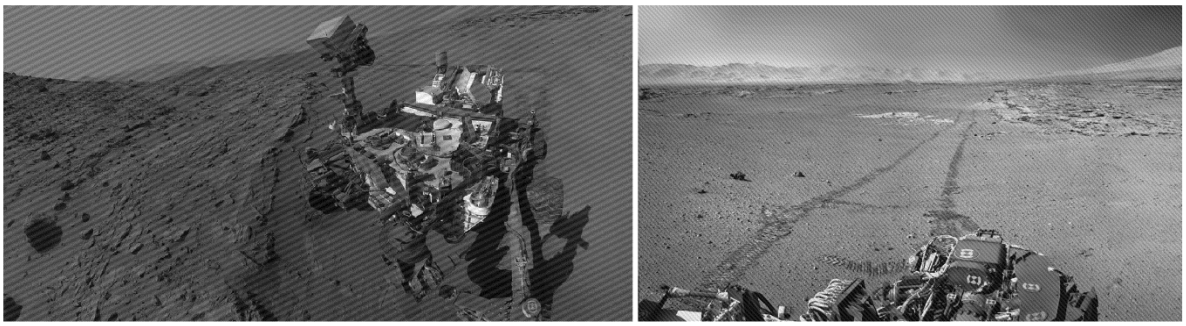

Figure 12 Images of NASA's Mars rover, Curiosity, degraded with sinusoidal noise

c. Load the image "vertical_blinds_garden.jpg" and display the corresponding spectrum. As you can see, the blinds have obscured the view. Because of its natural pattern, one can use image restoration techniques in frequency domain to deal with this problem. Design and apply a notch filter to reduce the effect of this periodic pattern from the image, and display the results.
d. Repeat part c. with the image "vertical_blinds_city.jpg".
e. Repeat part c. with the image "vertical_blinds_plantation.jpg".
f. Repeat part c. with the image "vertical_blinds_yard.jpg".
Note: remember that the input images in part c. to part f. are in RGB space.

Figure 13 From left to right, input images of part c. to part f. In all images, a periodic pattern - which has obscured a view - is visible

Allowed MATLAB functions: `imtool()`, `mat2gray()`, `fft2()`, `fftshift()`,

7. Dealing with Blur using Wiener Filter (8 Pts.)

Keywords: *Wiener Filter, Gaussian Blur, Motion Blur*

Wiener Filter is arguably the most popular technique for removing blur effect in images, caused by linear motion or unfocussed optics. The Wiener filter assumes image and noise as random process, and tries to minimize the mean square error between them.

Your goal in this problem is to use Wiener filter to reduce the effect of blur in images. You are provided with blur filters information as well.

a. Load the image "donald_and_father.jpg". The image was blurred using a Gaussian filter of size 25 with parameter sigma equals to 2. Remove the effect of blurring from the image.
b. Load the image "trump_truck_driving.jpg". This time, the image blur type is motion blur, with the length of motion (`len` in MATLAB) set to 30, and angle (`theta` in MATLAB) to zero. Remove the effect of blurring from the image.

Figure 14 Blurred image of Trump alongside his father in his college graduation ceremony

Figure 15 Blurred image of Trump behind a truck

Note: The input image in part b. is in RGB space, so the Wiener filter must be applied to each channel, then the final image must be reassembled.

Hint: In each part, using the provided filter parameters, you just have to acquire corresponding filter in the frequency domain, and then apply Wiener filter using an appropriate value for parameter `k`.

Allowed MATLAB functions: `fft2()`, `fftshift()`,`ifft2()`, `im2double()`

8. Restoration and Enhancement of Historical Photos (20 Pts.)

Keywords: *Image Enhancement, Image Restoration*

Due to incapability of hardware and lack of technology, historical photos hugely suffer from different types of degradations. **Image Restoration** and **Image Enhancement** techniques are powerful tools to improve these photos, making them more appropriate for publishing or researching purposes.

Figure 14 The oldest surviving camera photograph, known as "View from the Window at Le Gras", taken in 1826 or 1827 by Nicéphore Niépce [link]. Left: original plate. Right: enhanced version

In this problem, you are provided with some of the oldest surviving photos of the history, and your task is to increase their quality using all you have learnt from image restoration and image enhancement techniques.

a. Please load the image "le_gras.jpg". Considering the degradation you observe, use any image enhancement (like histogram equalization, sharpening filters, etc.) or image

restoration (like median filter, Wiener filter, etc.) techniques you wish to improve the quality of the image. You are free to apply more than one method as well. Display all intermediate versions of your work, and include them in the report.

b. Repeat part a. for the image “still_life_in_studio.jpg”.
c. Repeat part a. for the image “boulevard_du_temple.jpg”.
d. Repeat part a. for the image “robert_cornelius_selfie.jpg”.
e. Repeat part a. for the image “william_jennings_lightning.jpg”.
f. Repeat part a. for the image “john_quincy_adams.jpg“.
g. Repeat part a. for the image “berkowski_solar_eclipse.jpg“.
h. Repeat part a. for the image “louis_daguerre.jpg“.
i. Repeat part a. for the image “self_portrait_as_a_drowned_man.jpg“.
j. Repeat part a. for the image “tartan_ribbon.jpg“.

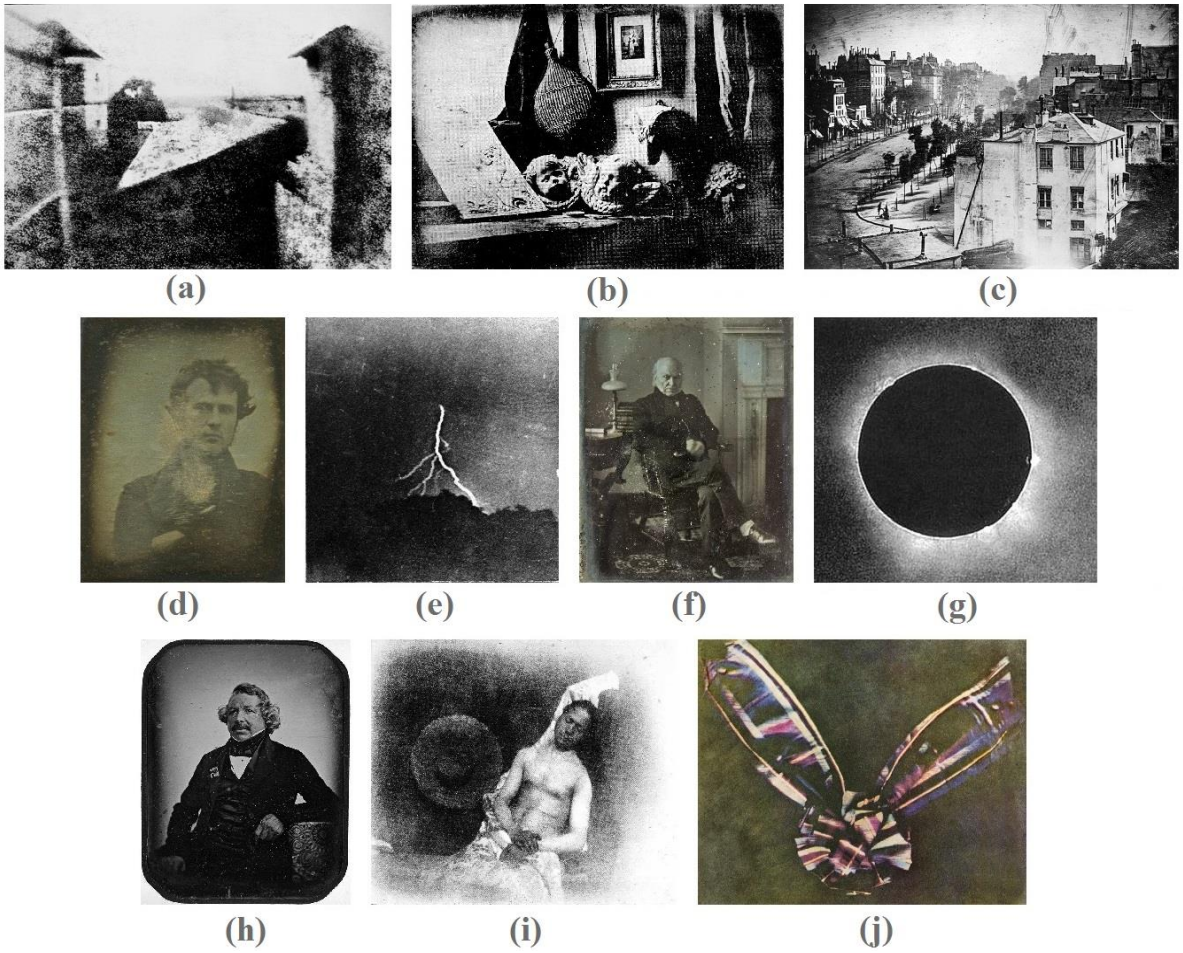

Figure 15 Some of the oldest known surviving photographs in the history, given as the input images of this problem (a) Oldest known photograph in the history (1826) (b) Some plaster casts in Louis Daguerre’s room (1837) (c) First ever picture of a living person (on the bottom-left of the image) (1838) (d) Oldest selfie (1839) (e) First photo of a lightning (1887) (f) First known photo of a US President, John Quincy Adams (1843) (g) First photo of a solar eclipse (1851) (h) Louis Daguerre, one of the fathers of photography (1830) (i) First hoax photograph, known as “Self Portrait as a Drowned Man” (1840) (j) First color photograph, taken of a tartan ribbon (1861)

Note: Please keep images format as is.

Allowed MATLAB functions: No restrictions; all MATLAB functions are allowed

9. Some Explanatory Questions (8 Pts.)

Please answer the following questions as clear as possible:

a. What is the difference between additive noise and multiplicative noise? Which one does "salt-and-pepper" noise belong to?
b. Imagine you want to remove a periodic noise from an image, and you are not allowed to use frequency domain filtering. What type of filter are you going to use? How does the frequency of the noise affect your kernel size?
c. Imagine you want to remove a Gaussian noise from an image, and you are not allowed to use spatial domain filtering. What type of filter are you going to use? How does the mean and variance of the noise affect your filter parameters?
d. Why does the last column of an affine transformation matrix consist of two '0's and a '1'?
e. Write an appropriate transformation matrix for a transformation consisting of a horizontally scaling of 2x, a counter-clockwise rotation by 60 degrees and a vertically translation by 20 pixels.

Good Luck!
Ali Abbasi