Digital Image Processing (2021 spring)
HOMEWORK ASSIGNMENT #1 Image Enhancement and Noise Removal
environment: C++, opencv4
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Problem 1: WARM-UP

(a) Convert sample1.jpg to a grayscale image named 1_result.jpg.

To convert the image into the grayscale image, use the following weighted method formula and calculate the gray-level of each pixel for the grayscale image.

$$Grayscale = 0.299R + 0.587G + 0.114B$$

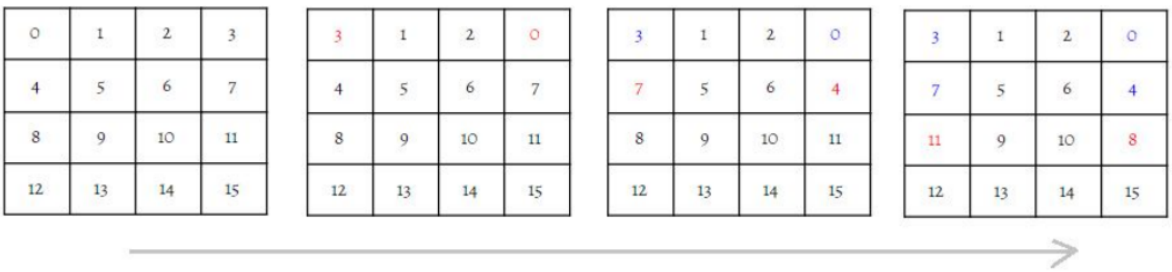

sample1.jpg


1_result.jpg

(b) perform horizontal flipping on sample1.jpg and output the result as 2_result.jpg.

To perform horizontal flipping, swap the value of the pixel a to pixel b in the way below.

$$I'(i,j) = I(i, w - j - 1) \qquad w = width\ of\ image$$




sample1.jpg


2_result.jpg

Problem 2: IMAGE ENHANCEMENT

(a) Decrease the brightness of sample2.jpg by dividing the intensity values by 5 and output the image as 3_result.jpg.

$$I'(i,j) \;=\; I(i,j)\,/\,5$$

sample2.jpg

3_result.jpg

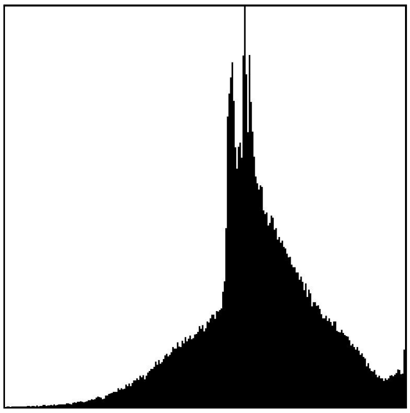
(b) Increase the brightness of 3_result.jpg by multiplying the intensity values by 5 and output the image as 4_result.jpg.

$$I'(i,j) \;=\; 5 \cdot I(i,j)$$

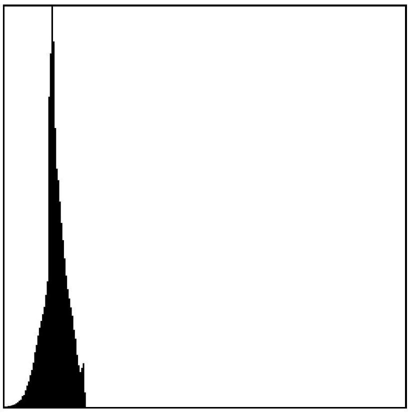
3_result.jpg

4_result.jpg

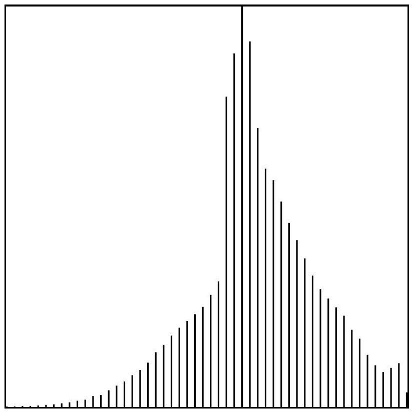
(c) Plot the histograms of sample2.jpg, 3_result.jpg and 4_result.jpg. What can you observe from these three histograms?



sample2.jpg (1:6)



3_result.jpg (1:24)



4_result.jpg (1:24)

The ratios are different

After decreasing the brightness of sample2.jpg by dividing the intensity values by 5, the range of intensity values becomes [0,51] and the distribution becomes denser. After increasing the brightness of 3_result.jpg by multiplying the intensity values by 5, the range of intensity values becomes[0,255] again. However, the intensity values of 4_result.jpg are multiples of 5. So, the distribution becomes sparser. The distribution of 4_result is similar to sample2.jpg, so they look the same.

(d) Perform global histogram equalization on sample3.jpg and output the results as 5_result.jpg.

Motivation

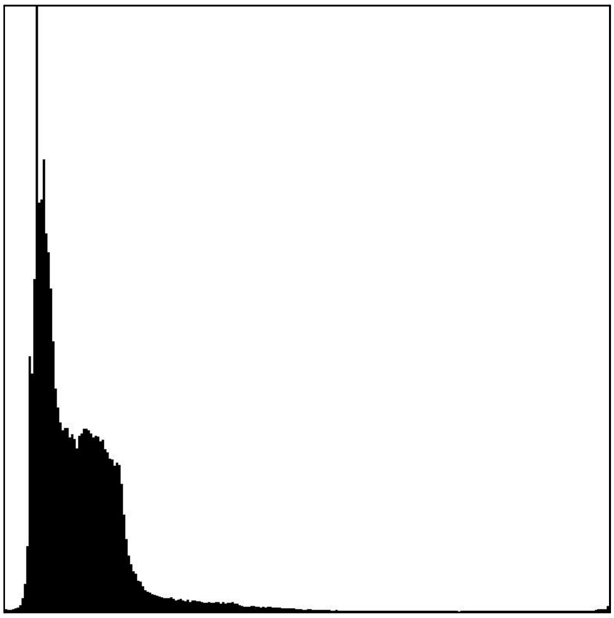
According to the sample3.jpg and its histogram, we can see that the distribution is closer to 0. It represents that the image is too dim. An ideal image has an average distribution, so we can implement histogram equalization to enhance the image.

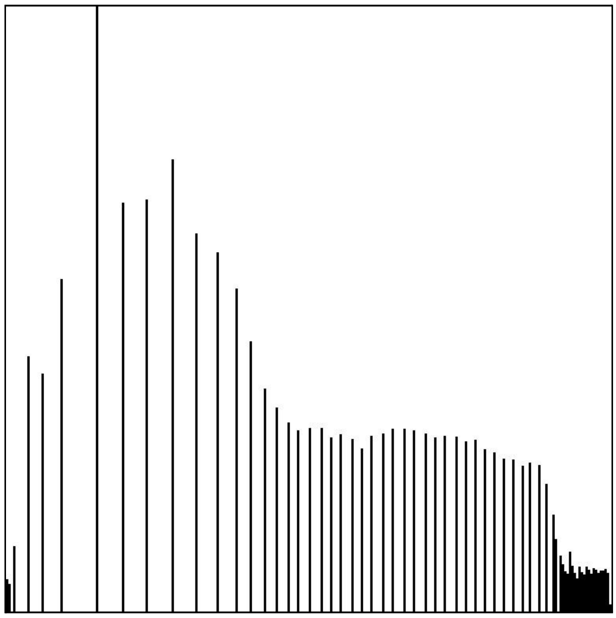
Method

i. Calculate the histogram and PDF of the gray-level of the image.
ii. Use PDF to calculate the CDF.
iii. Use the result of CDF to obtain the look-up table.
iv. Apply the new value of each pixel via the look-up table.

sample3.jpg

5_result.jpg





(e) Perform local histogram equalization on sample3.jpg and output the results as 6_result.jpg.

Motivation

Since overexposed exists in global histogram equalization and some of the structure is missing, local histogram equalization can enhance the image locally and avoid overexposed or underexposed.

Method

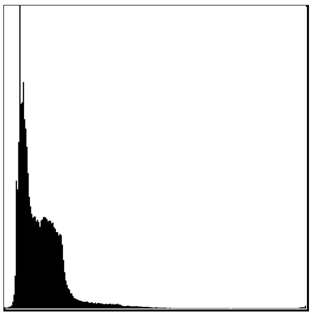
The implementation steps are similar to (d) but we perform the steps in 30x30, 60x60, 90x90 neighborhood regions respectively.

sample3.jpg

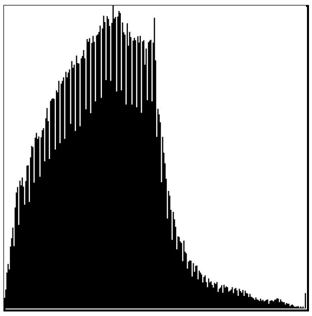
6_result.jpg (30x30)

6_result.jpg (60x60)

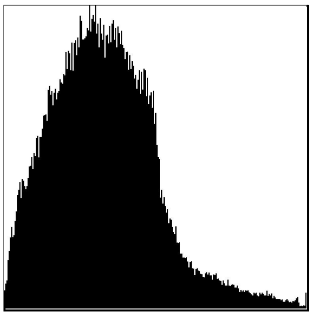
6_result.jpg (90x90)



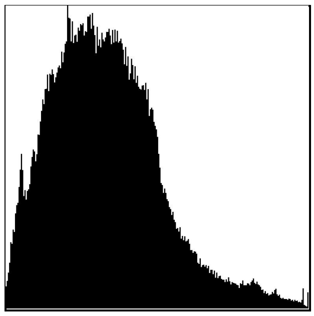
sample3.jpg



6_result.jpg (30x30)

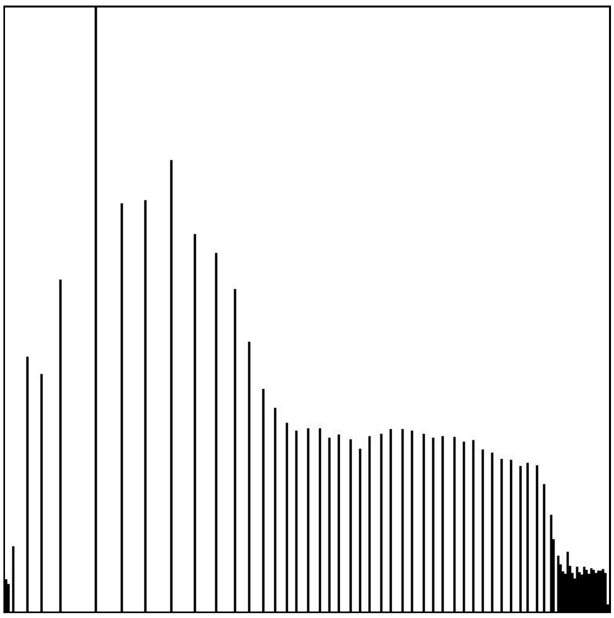


6_result.jpg (60x60)

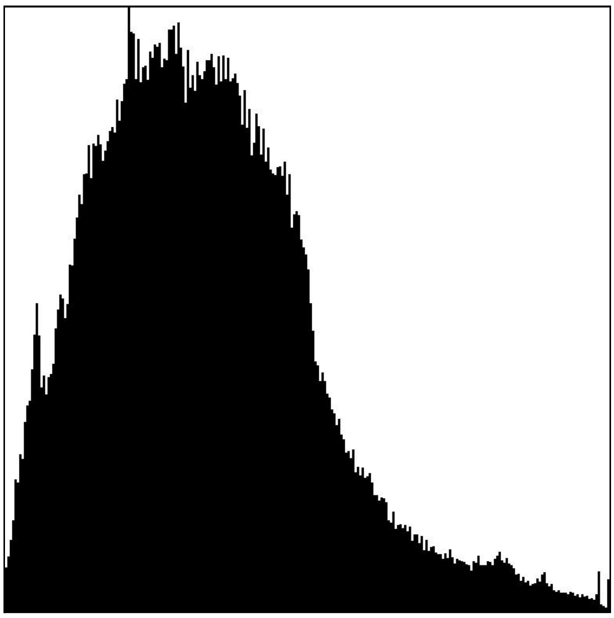


6_result.jpg (90x90)

(f) Plot the histograms of 5_result.jpg and 6_result.jpg. What is the main difference between local and global histogram equalization?



5_result.jpg



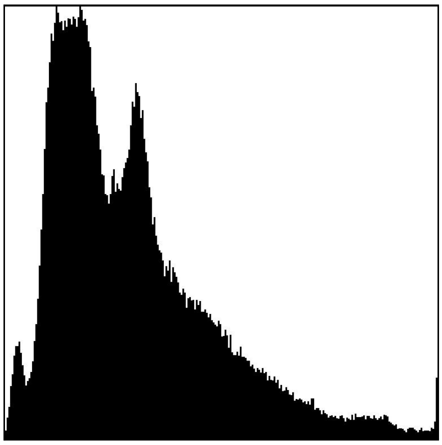
6_result.jpg

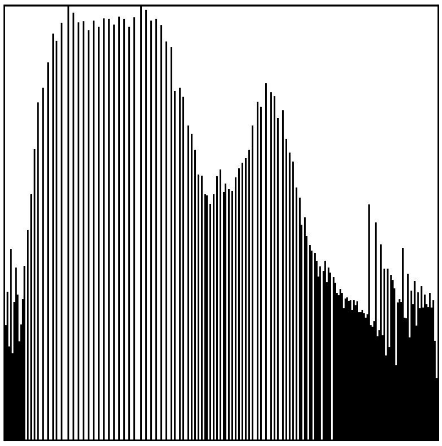
The distribution of global histogram equalization is sparser than local histogram equalization and the distribution is dense at the part of the high-intensity level.
It represents that overexposed exists in the resultant image after global histogram equalization. It may lose its structure and characteristics. In local histogram equalization, the contrast of the image is enhanced but the noise is also amplified.

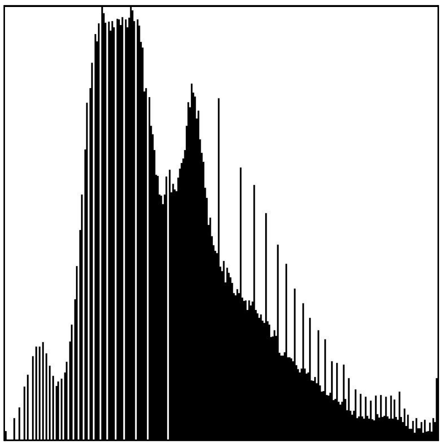
(g) Design a transfer function to enhance sample4.jpg. Show the resultant image(s) and the corresponding histogram(s). Please provide some discussions on the results as well.

To enhance sample4.jpg, I have tried global histogram equalization and power-law function. I haven't chosen local histogram equalization since it will amplify the noise and affect the clarity of the image.

In the resultant image with global histogram equalization, the contrast is higher than the power-law function. However, overexposed and underexposed exist. In the power-law function, the contrast is lower but the structure and characteristic are still reserved. Therefore, I have chosen the power-law function for enhancing sample4.jpg.



original



GHE

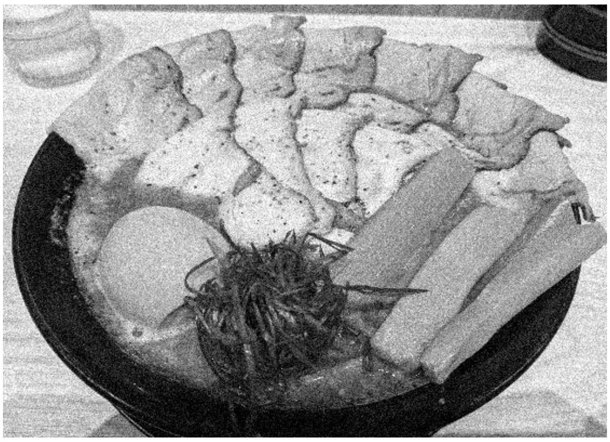


power-law

Problem 3: NOISE REMOVAL

(a) **Design proper filters to remove noise from sample6.jpg and sample7.jpg. Please detail the steps of the denoising process and specify all the corresponding parameters. Provide some discussions about the reason why those filters and parameters are chosen.**

sample6.jpg

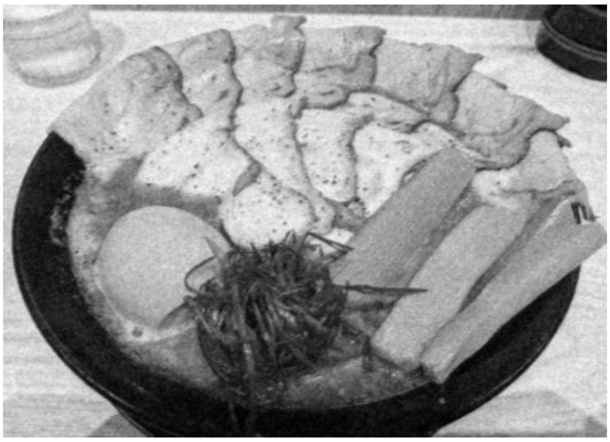
Since sample6.jpg is an image with uniform noise, I have chosen the low-pass filter to remove noise. If we use a 5x5 low-pass filter, the resultant image is vaguer than using a 3x3 low-pass filter. Therefore, we can use a 3x3 low pass filter to denoise and avoid over blurred. After choosing the 3x3 filter, I have tried to use three different filters to perform noise removal. To conclude, the **3x3 low-pass filter with kernel 2** has the best performance of noise removal.



sample6.jpg (uniform noise)

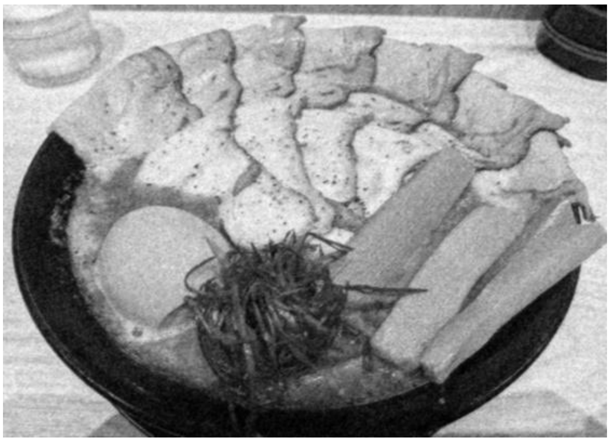
$$H = \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \quad H = \frac{1}{10}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 2 & 1 \\ 1 & 1 & 1 \end{bmatrix} \quad H = \frac{1}{16}\begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}$$

kernel 0 kernel 1 kernel 2

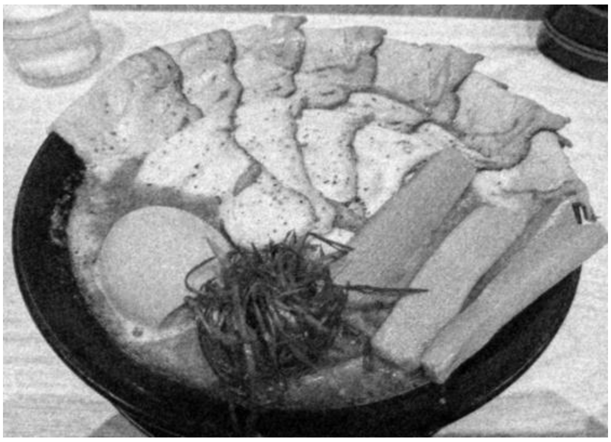


3x3 low pass filter (kernel 0)

5x5 low pass filter



3x3 low pass filter (kernel 1)



3x3 low pass filter (kernel 2)

sample7.jpg
Sample7.jpg is an image with impulse noise. Therefore, I have tried to use outlier detection and median filtering with different parameters as shown below.

For the median filter, all of the salt and pepper noise is removed but the image is blurred. Using a 5x5 median filter is vaguer than using a 3x3 median filter.

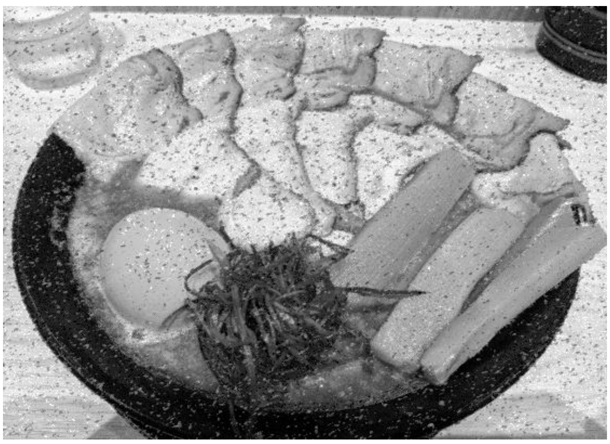
For outlier detection, the performance of a 3x3 neighborhood kernel with threshold 65 is much better than the others. However, there are still noises in all of the resultant images with outlier detection.

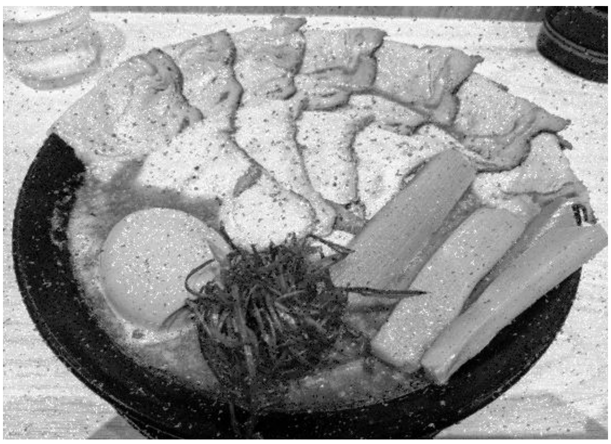
To conclude, I think the performance of the **3x3 median filter** is the best. Although it is a little bit blurred, all of the noise is removed and the structure of the resultant image is still clear.

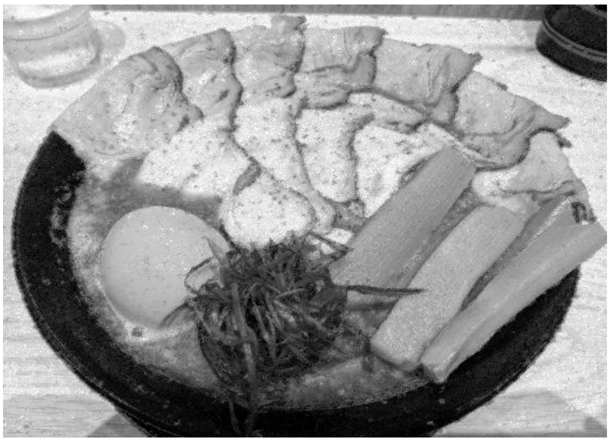

sample7.jpg (impulse noise)


3x3 median filter

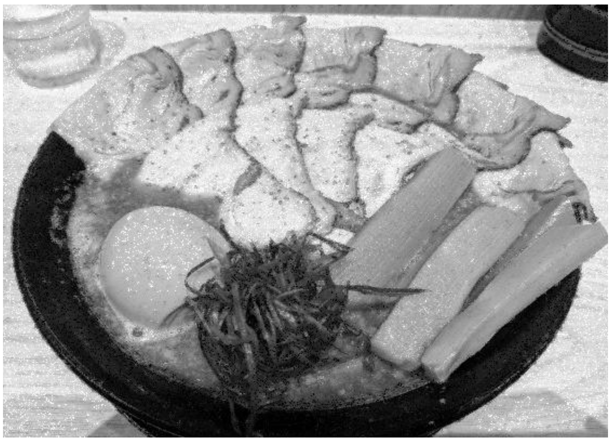

5x5 median filter


3x3 outlier filter threshold = 50


3x3 outlier filter threshold = 65



5x5 outlier filter threshold = 50



5x5 outlier filter threshold = 65

(b) Compute the PSNR values of 8_result.jpg and 9_result.jpg and provide some discussions.

```
sample6 = 22.3772
8_result_lowpass_3x3_kernel_0 = 26.7181
8_result_lowpass_5x5_kernel_0 = 24.8721
8_result_lowpass_3x3_kernel_1 = 27.1189
8_result_lowpass_3x3_kernel_2 = 27.2833

sample7 = 11.7596
9_result_median_3x3 = 26.5866
9_result_median_5x5 = 23.5223
9_result_outlier_3x3_t_50 = 23.0573
9_result_outlier_5x5_t_50 = 25.5109
9_result_outlier_3x3_t_65 = 24.141
9_result_outlier_5x5_t_65 = 25.4843
```

PSNR of 8_result.jpg = 27.2833 (3x3 low-pass filter with kernel 2)
PSNR of 9_result.jpg = 26.5866 (3x3 median filter)

Obviously, the performance of the 3x3 low-pass filter with kernel 2 and 3x3 median filter is the best in sample_6 and sample_7 respectively. The PSNR values represent that the resultant images have a higher quality of reconstruction.

Compared with sample6 and sample7, the difficulty of removing impulse noise is much higher than uniform noise since we have to try different methods to investigate the best method and parameter to remove impulse noise. And it is not easy to remove all of the noises in the image.

Reference / supplement:

Problem 1

1. Grayscale formula
   https://www.dynamsoft.com/blog/insights/image-processing/image-processing-101-color-space-conversion/

Problem 2

1. Histogram implementation

```
Mat histogram(Mat img, int bin[])
{
    int max = 0;

    //pixel value count
    for (int i = 0; i < img.rows; i++)
    {
        for (int j = 0; j < img.cols; j++)
        {
            bin[img.at<uchar>(i, j)]++;
        }
    }

    //highest intensity
    for (int i = 0; i < 256; i++)
    {
        if (bin[i] >= max)
        {
            max = bin[i];
        }
    }

    //create graph
    Mat graph(768, 768, CV_8UC1, Scalar(255));
    float ratio = max / 768.0;
    for (int x = 0; x < 256; x++)
    {
        for (int y = 0; y < bin[x]; y++)
        {
            graph.at<uchar>(767 - floor(y / ratio), x * 3) = 0;
            graph.at<uchar>(767 - floor(y / ratio), x * 3 + 1) = 0;
            graph.at<uchar>(767 - floor(y / ratio), x * 3 + 2) = 0;
        }
    }

    return graph;
}
```

2. Global histogram equalization
   https://jason-chen-1992.weebly.com/home/-histogram-equalization

3. Local histogram equalization (Adaptive histogram equalization)
   https://en.wikipedia.org/wiki/Adaptive_histogram_equalization

Problem 3

1. PSNR
   https://en.wikipedia.org/wiki/Peak_signal-to-noise_ratio