EE569 Digital Image Processing

**HOMEWORK #1**

**HOMEWORK – Introduction to Digital Image Processing**

**Issued: 13/01/2020 Due: 27/01/2020**

# Problem 1: Image Demosaicing and Histogram Manipulation (50%)

1. **Bilnear Demosaicing (10%)**

**Motivation**

The aim is to practice demosaicing method that can transform gray-scaled image to colorful RGB image. The bilinear transformation method is the simplest way to transform the gray-scaled image into the RGB image. The color type of three channels of the pixel depends on the position of processed pixel and its neighboring pixels. The formula to compute the pixel color value varies when position of the pixel changes. Hence, if-else argument should be designed to compute pixel value with different position in the image so that the color type of pixel can be got.

The formula show the key computation procedure for each pixel intensity value.

Each pixel intensity value ofcertain coloris estimated by the neighboring pixels with the same color type. The pixel intensity value in three channels is computed with the same procedure because the edge is extended to avoid different solution for intensity value estimation.

**Approach and procedure**

*This is the first problem to be solved. Hence, the basic C++ program method like inputting file, allocating memory for array to process problem generally will be introduced firstly. The procedure for following problem below will be explained again. The steps for setup are almost same for each problem.*

Before starting computing, memory is allocated to store the initial image. To prevent different manipulation on the pixels on the edge, the original image is extended with mirror rule. The implementation of mirror rule is to mirror pixel with the first column. For example, the intensity value of pixels in the column at extended edge neighboring the first column of original image has the same value with the first column pixels. In that case, all pixels at the extended edge are mirrored by the first pixel column. The function *extend2DImage()* has finished this function.

The followings are the concise introduction to the general function:

*read2DImageFile()*

IO function to read image data to 2-dimensional array

*write2DImageFile()*

IO function to write processed image data to a file

*extend2DImageEdge()*

extend image edge to ensure the same operation for the pixels. The extension rule uses the first column as the mirror column for the closest. When the pixels is looped to solve some problems, the index of pixel is not the original pixel. For row and column index, the pixel of extended image can be accessed by the original row and column index in addition to the size of the edge. There are also functions to handle 3-D image with same technique.

The RGB image pixel color value is computed by averaging the pixel value with same color type. For green, it is different from red and blue because there are only two pixel with same type green neighboring.

**Results**

The result is amazing. The obtained image is colorful. The computation cost is low. There are O() complexity for the whole computation procedure. The Figure 1.1.1 shows obtained image computed by the Bilinear algorithm from gray-scaled image. The Figure 1.1.2 shows the original image. With comparison to the original image, the obtained image is more colorful in some area. The grass is more green. In Figure 1.1.3, when the camera is zoomed, the distribution of color pixel intensity value of obtained image is more equal than the distribution of original image.

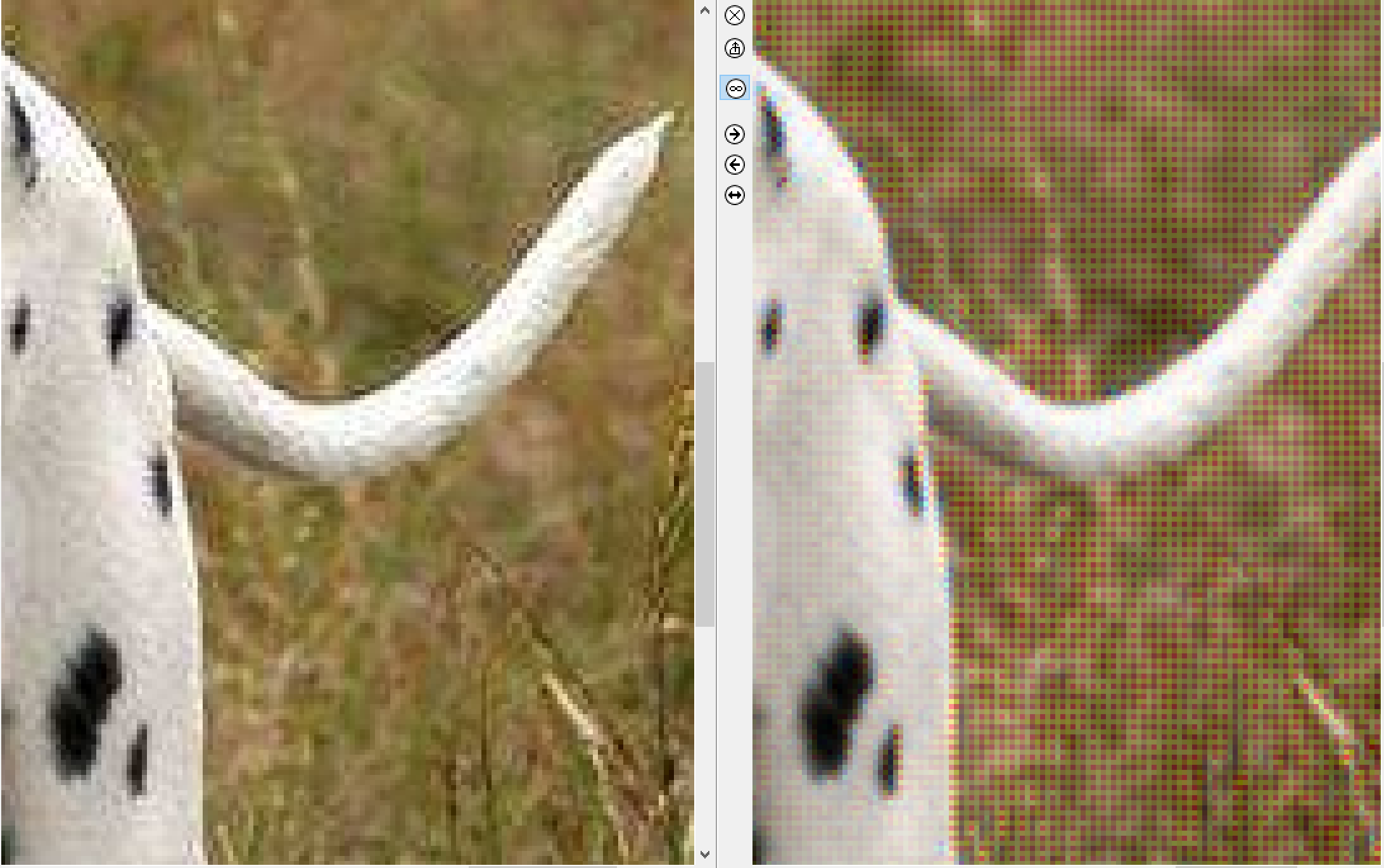
图片包含 小狗, 草, 动物, 哺乳动物

描述已自动生成 图片包含 草, 小狗, 户外, 田野

描述已自动生成

**Figure 1.1.2 original image**

**Figure 1.1.1 obtained image**



**Figure 1.1.3 colorful artifact compared with the original image**

**Discussion**

The computation of the pixels depends on the position of the pixel. The averaging process is safe. There is overflow for the final computed pixel. The maximum pixel value is 255. The addition for C++ is 2 byte operator space. The final result for each pixel will be within 0-255 because the total summation will be divided by 2 or 4, so there is no overflow.

**Answers**

1. In Figure 1.1.1 and Figure 1.1.2, you are shown with the obtained dog picture and the original dog image. Compared with the original image, the obtained image is more colorful. The grass is much greener. More shapes can be viewed from scanning.
2. Problem may be caused by the local average process for computation. The bilinear method ignores the global hue for the image, the color seems to be distributed equally from the obtained image.
3. **Malvar-He-Cutler (MHC) Demosaicing (20%)**

**Motivations**

The MHC method to demosaiced image is to add small computation compliment when we compute color value of three channels for the image.

**Approach and procedure**

1. Judge the primary color of pixel.
2. Compute difference between value of original color and neighbor color.
3. Compute estimated value for other color of the pixel.
4. Loop the above three steps for all pixels and get the image.

The computation procedure for difference value between original color and neighbor color depends on the color category of the pixel, so the specific function is chosen to compute the delta value for the pixel. There may be overflow for the unsigned char data type, so a compliment function needs to revise the computation result for each pixel

**Results**

Figure 1.2.1 shows an image with black background. Some area of the obtained image contains much more colorful color that is stronger than the original image.

A brown and white dog standing on top of a grass covered field

Description automatically generated

**Figure 1.2.1 Obtained Image with MHC method**

**A brown and white dog standing in the grass

Description automatically generated**

**Figure 1.2.2 original image**

**Discussion**

Overflow happens when the increment compliment estimation by the neighboring pixels is computed. Hence, the negative value may appear. The possible result can be negative for the pixel value. This cause the overflow for the unsigned char type because the unsigned char value can not be negative. The uncorrelated value causes several peak pixel with pure red, blue that is not correlated to the neighboring pixel value. The solution to eliminate this noise is to combine two methods above. When the negative value is got, average method can be chosen.

**Answers**

1. The figure above gives the clear comparison between the original image and image processed by Bilinear Demosaicing algorithm
2. The artifacts are the image that are more colorful than the other image processing.

**c). Histogram manipulation(10%)**

**Motivation**

The aim of histogram manipulation is change the distribution with respect to pixel value. The foundation method to implement it is to construct a transformation function that maps the pixels for the same value to another pixel value. The problem provides two principle for us to construct transformation array for the pixel value mapping. The method A is to use cumulative probability theory. The probability density for each pixel value should be uniformed so that the probability distribution can be transformed to uniform distribution. [1].

**Approach and procedure**

**Method A transfer function based histogram equalization**

* 1. compute the number of pixels corresponding to dedicated one gray-scaled value
  2. get the histogram to describe the distribution between pixels numbers and gray-scaled intensity value
  3. sum from the histogram value of pixel with 0 intensity value to the wanted histogram value and then give the sum histogram value for each pixel intensity value.
  4. apply normalized transfer function based on the sum histogram to transfer current image pixels with certain intensity value to other intensity value.

*TransferFunctionBasedHistogramEqualization()*

Construct transfer array to map the original pixels to the equalized pixels

*histogramCountByChannel()*

count the number of pixels with the same intensity value, each channel is counted separately

*writeHistogramArray()*

write histogram array to the file for convenient plot by matlab

*poltTransformArray.m*

plot the transform array for each channel by matlab

**Method B cumulative probability based histogram equalization**

1. rearrange each pixel position. The pixel with the same intensity value is positioned in the section of array.
2. row and column index in the image of pixel and intensity value of pixel is separately recorded in the array.
3. The pixel value is reallocated from 0 to 255 sequentially.
4. Extract the data from the reordered array and put them into 2 dimensional array for image output

*RandomPickHistogramEqualization()*

*RandomPickBasedHistogramEqualizationByChannel()*

**Results**

Figure 1.3.1 shows the histogram distribution of the original image. Figure 1.3.2 shows the histogram of the image processed by method A. From comparison between two figures, the pixels value distribution is transferred more equally. The contrast of image is improved from the comparison between Figure 1.3.5 and Figure 1.3.6. The transfer function itself is almost a linear function that maps pixels of original image to the pixels processed by the method A. In Figure 1.3.4, the values in the histogram of three channels are the same. The method B transfers the probability distribution of pixels value to the uniform distribution. Both methods are quite effective to transfer the original image to the image which has more contrast.

**A close up of a map

Description automatically generated**

**Figure1.3.1 histogram of original Toy.raw image**

**A screenshot of a cell phone

Description automatically generated**

**Figure 1.3.2 histogram of obtained Toy\_a.raw by method A**

A picture containing text, sky, outdoor

Description automatically generated

**Figure 1.3.3 mapping transfer function**

A close up of a device

Description automatically generated

**Figure 1.3.4 histogram of obtained Toy\_b.raw by method B**A stuffed animal on a table

Description automatically generatedA large brown teddy bear sitting on a table

Description automatically generated

**Figure 1.3.5 the original toy image**

**Figure 1.3.6 obtained toy image with method A**

**A picture containing coffee, table, indoor, cup

Description automatically generated**

**Figure 1.3.7 obtained Toy\_b.raw image with method B**

A bunch of different types of map

Description automatically generated

**Figure 1.3.8 cumulative histogram for channels transferred by method B**

**Discussion**

The first try to get RGB image does not consider the boundary problem, some overflow may appear because the intensity value result is much bigger than 255 or much smaller than 0. The type that is used to store each pixel value is unsigned char which is only allocated one byte. The compliment method is to give pixel value 255 or 0 when big overflow or negative overflow happens.

**Answers**

1. The figure 1.3.1 shows the histogram for the original image. Three channels are separately described by one histogram distribution table.
2. Figure 1.3.3 plots the transfer function of method A
3. Figure 1.3.8 plots cumulative histogram of method B
4. The histogram of original image shows the number of pixels whose intensity value is almost 0 and 255, quite white and black pixels are much more. This concentration on both black and white sides causes contrast of image is not sufficient to show the details of some area. The histogram equalization is to redistribute the histogram distribution of pixel value and make contrast of different region in image show more detailed information which can be clearly seen by naked eye. There are some pixels of peak value in some channel.

# Problem 2: Image Denoising (50%)

1. **Basic denoising methods (10%)**

**Motivation**

This is the simplest method among the problems to denoise image. Each pixel are obtained by averaging the neighboring pixels with the same weight. This weighs neighboring pixels equally by default. This assumption is defective when there are some discontinuous changes in the image.

**Approach and procedure**

*linear\_filter()*

loop all pixels to estimate them with uniform weight filter

*aver2DImage()*

compute intensity value of pixel by averaging all neighboring pixels with uniform weight

*GaussianFilter()*

Loop all pixels to estimate them with gaussian weight filter

*compGaussianPixel()*

compute intensity value of pixel by averaging all neighboring pixels with gaussian weight

**Results**

Figure 2.1.1 shows the original pure image and the denoised image by bilinear. Figure 2.1.2 shows a set of images whose window size is tuned large. The sets of images show that when the window size is more large, the processed image is more obscure. The PSNR is lower when the window size is much larger. The trader-off should be placed on the final tuning parameters. Table 2.1.1 shows the debug parameter for the image denoising. The PSNR is computed by comparison between the original image and the denoised image. The window size is firstly tuned to improve performance. After window size gives good performance, then the type of filter is changed for comparison. From the table, we can see the gaussian filter performs well when the window size is large for both filter. The uniform filter works bad when the window size is very large. By contrast, the PSNR can still keep satisfying result when window size is 20 for gaussian filter.

**A person lying on a blanket

Description automatically generatedA group of corn

Description automatically generated**

**Figure 2.1.1 the denoised image with method A and the original image**

**A picture containing person, indoor, sitting

Description automatically generatedA picture containing indoor, person

Description automatically generatedA picture containing bed, indoor, laying

Description automatically generated**

**Figure 2.1.2 the denoised image set by uniform filter**

**A picture containing person, indoor, sitting

Description automatically generatedA picture containing person, indoor, clothing

Description automatically generated**

**Figure 2.1.3 the denoised image set by Gaussian filter**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **ID** | **Filter type** | **Window size** |  | **PSNR** | **comment** |
| 1 | uniform | 4 | n/a | 19.0771 |  |
| 2 | uniform | 6 | N/A | 18.8386 |  |
| 3 | uniform | 8 | N/A | 18.6364 |  |
| 4 | gaussian | 10 | N/A | 18.4677 |  |
| 5 | gaussian | 4 | 1 | 19.3856 |  |
| 6 | gaussian | 6 | 1 | 19.3827 |  |
| 7 | gaussian | 10 | 1 | 19.3825 |  |
| 8 | gaussian | 20 | 1 | 19.3825 |  |
| 9 | gaussian | 10 | 10 | 18.5714 |  |
| 10 | gaussian | 4 | 5 | 19.0911 |  |

**Table 2.1.1 debug parameters for uniform and gaussian filter**

**Discussion**

The window size can be tuned to make the algorithm perform better. The PSNR is generated by program and when PSNR is high, the performance of algorithm is much better. Table 2.1.1 shows that only small window size can make both of algorithms work well. When the window size is tuned larger, which means more pixels are considered as neighboring pixels in the window, the gaussian filter is less influenced by enlargement of the window size. As the window size become larger, the performance gets worse for both filter. The decline of PSNR is caused by the addition of much noisy neighboring pixels.

**Answers**

1. The image contains gaussian noise.
2. The difference between filter of uniform weight function and gaussian weight function is the window size tuning. The filter of uniform weight performs worse when the window size is large. In contrast, there are only slight effect on PSNR performance for gaussian filter. The reason is that the gaussian weight function take the position of neighboring pixel into consideration to compute weight. The weight will be very small for large distance from the index position of the processed pixel. There is another parameter for gaussian filter. In table 2.1.1, it works well when parameter is 1. There is no improvement when is tuned larger than 1.
3. **Bilateral Filtering (10%)**

**Motivation**

Bilateral filter compute weight based on Gaussian Probability distribution. It measures the pixels and neighboring pixels by their relative position and intensity pixel value relationship. Both effects on the pixel relationship decides the gaussian coefficients for the pixel intensity value. When the distance between measured pixel and target pixel is large, the weight for the measured pixel will be small. The extension of effect of both elements on the algorithm performance is based on the parameter of standard variance that can be tuned.

**Approach and procedure**

1. Loop for each pixel to compute denoised intensity value
2. Compute the weight for each pixel in the window
3. Sum up and average the pixels in the window to get the intensity value

*bilateral\_filtering()*

loop all pixels to get the estimated results from *computeBilateralFilteredPixel()*

*computeBilateralFilteredPixel()*

compute pixel intensity value by summing up all gaussian coefficients multiplied by the pixel intensity value and normalizing by summing up all gaussian coefficients themselves

*computeGaussWeight()*

compute the gaussian function result by the relative distance between processed pixel and the selected pixel in the window loop procedure.

The more detailed procedure can be checked by scanning the program code.

**Results**

In Figure 2.2.1 shows the comparison of denoised image with different standard variance. At first glance, the right side image performs well in denoising. Figure 2.2.2 shows the comparison between denoised image with different window size. The right side is the denoised image with large window size. Hence, the large window size for the bilateral algorithm has benefits on improvement of performance. Table 2.2.1 summarizes the PSNR change trends as some parameters change. The Figures present different comparison between these parameters.

A picture containing person

Description automatically generatedA picture containing person, indoor

Description automatically generated

**Figure 2.2.1**

A picture containing person, indoor

Description automatically generatedA picture containing person, indoor

Description automatically generated

**Figure 2.2.2**

**A picture containing person, indoor

Description automatically generatedA picture containing person, indoor

Description automatically generated**

**Figure 2.2.3**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ID | window size |  |  | PSNR | Citations |
| 1 | 4 | 1 | 10 | 17.7505 |  |
| 2 | 4 | 1 | 20 | 18.3536 | Figure 2.2.1 |
| 3 | 4 | 1 | 30 | 18.9423 | Figure 2.2.1 |
| 4 | 4 | 1 | 50 | 19.4444 |  |
| 5 | 4 | 1 | 100 | 19.5138 | Figure 2.2.2 |
| 6 | 4 | 1 | 120 | 19.4876 |  |
| 7 | 4 | 1 | 150 | 19.4552 |  |
| 8 | 10 | 1 | 100 | 19.5159 |  |
| 9 | 20 | 1 | 100 | 19.5159 | Figure 2.2.2 |
| 10 | 10 | 5 | 100 | 19.0669 | Figure 2.2.3 |
| 11 | 10 | 2 | 100 | 19.3528 | Figure 2.2.3 |

**Table 2.2.1 the debug parameter for bilateral filter**

**Discussion**

As Table 2.2.1 shows, the perfect performance is given when the window size is around 10. There is no sharp improvement when window size continues to enlarge because gaussian coefficient declines sharply with the enlargement of distance between pixels. describes the distance from the processed pixel and neighboring pixel. Hence, the its value is around 1 as the pixel from far distance plays has slightly effect on the processed pixel value. describes the difference between processed pixel intensity value and neighboring pixels value. The range of these pixel values is from 0 to 255. It is reasonable that the performance is perfect when is around 100.

**Answers**

1. the figures and program shows the result
2. The are different. describes the variance of relative position index. The better performance occurs at around 1. The describes the variance of pixel intensity value. The better performance occurs at around 75.
3. It has almost same performance with the algorithm in problem2(a). It has better performance if the parameter is tuned well, but the performance is just slightly higher. The highest PSNR is 19.51 which is slightly bigger than highest PSNR of filter in problem a.
4. **Non-Local Means(NLM) Filtering(10%)**

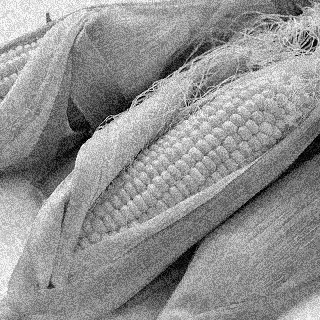
**Motivation**

The basic idea of NLM algorithm is to “build a pointwise estimate of the image where each pixel is obtained as a weighted average of pixels centered at regions that are similar to the region centered at the estimated pixel” [1]. The size of window for the processing pixel to compute the distance from the neighboring pixel and the window to compute the gaussian coefficients is different. The implementation for the algorithm is difficult. The result is not obviously improved.

**Approach and procedure**

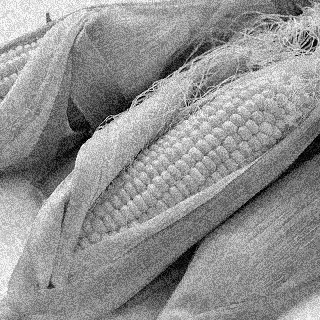
1. Compute image pixel value in the window size, make relative edge size addition for each pixel position index
2. For each pixel value computation, the patch window is constructed and loops the pixels in the patch window.
3. Compute the Euclidean distance based on the looping of pixels in the patch window between patch of processed pixel and neighboring pixel.
4. Transform the Euclidean distance to the gaussian coefficient for each neighboring pixel
5. Estimate pixel value
6. Loop for all pixels

**Results**

**A picture containing dog, indoor, hot

Description automatically generated**

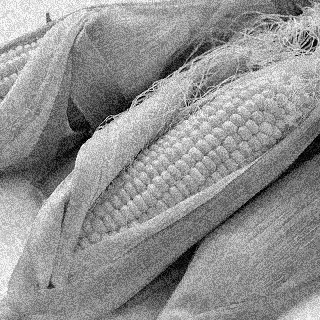
**Figure 2.3.1**

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**Figure 2.3.2**

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**Figure 2.3.3**

****

**Figure 2.3.4**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Id** | **window size** | **patch size** | **Parameter**  **h** | **Parameter** | **PSNR** | **Comment** |
| 1 | 6 | 4 | 10 | 10 | 19.3719 | Figure 2.3.1 |
| 2 | 6 | 4 | 1 | 10 | 17.6887 | Figure 2.3.1 |
| 3 | 6 | 4 | 20 | 10 | 19.1243 | Figure 2.3.4 |
| 4 | 6 | 4 | 10 | 20 | 19.2585 |  |
| 5 | 6 | 4 | 10 | 50 | 19.093 | Figure 2.3.2 |
| 6 | 6 | 4 | 10 | 25 | 19.2143 |  |
| 7 | 10 | 4 | 10 | 10 | 19.1479 | Figure 2.3.2 |
| 8 | 6 | 4 | 5 | 10 | 18.6428 | Figure 2.3.4 |
| 9 | 6 | 4 | 5 | 25 | 19.3354 |  |
| 10 | 6 | 4 | 5 | 50 | 19.3469 | Figure 2.3.3 |
| 11 | 6 | 4 | 5 | 100 | 19.2152 |  |

**Table 2.3.1**

**Discussion**

In Table 2.3.1, when the H parameter for each pixel weight is around 5 and standard variance for gaussian weight is around 50, the result of algorithm on noisy image is wonderful.

**Answers**

1. The h parameters for the initial weight for neighboring pixels decide the influence of patch size and standard variance parameter influence extent.
2. **Block matching and 3-D transform filter (10%)**

**Motivation**

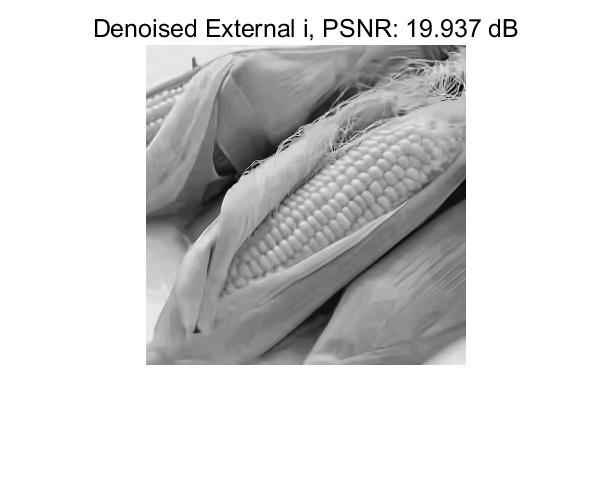
The BM3D algorithm is the most complex algorithm among the above denoising algorithm. This algorithm can be used in different complex scenario without careful analysis of image noise characteristics before. Hence, the algorithm performs well even if there is no tuning for the variance parameter.

**Approach and procedure**

It is hard to implement the algorithm. The open source matlab code [2] is used to implement algorithm. When the path of image file for input and output is added, all procedure is finished.

**Results**

Figure 2.4.1 and Figure 2.4.2 shows comparison between two images. The performance of BM3D is quite good. The algorithm works efficient without much effort to tune the parameter and the performance is quite good even at the first trial.

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**Figure 2.4.1 the denoised image and PSNR value by BM3D algorithm**

**A picture containing photo

Description automatically generated**

**Figure 2.4.2 the original noisy image and the PSNR with the pure image**

**Discussion**

The parameter for tuning is only the variance. Compared with algorithms above, the advantage of this algorithm is not to tune the many parameters to make PSNR indicator high. The algorithm is auto-adaptive based on the structure of its algorithm. It is difficult to implement the algorithm.

**Answers**

**Algorithm Steps**

1. match block of pixels to the reference one, and stack them to a group which is a 3D array

2. apply 3D transformation to the grouped pixels, attenuate the noise by hard-thresholding of the transform coefficients, invert the 3d transform to produce estimates of all grouped blocks, and return the estimates of the blocks to their original positions

3. compute the estimated pixel value by weighted averaging overlapping block-wise estimates

4.

**Implementation**

The implementation is based on the matlab framework [2]. Figure 2.4.1 and 2.4.2 shows result of using BM3D algorithm.

**(e). Mixed noises in color image (10%)**

**Motivation**

There is no specific code for this problem. Hence, all parts in this problem is to analyze the above denoising algorithm and compare their advantages and disadvantages. There is no panacea algorithm to denoise the image. The limit of the algorithm comes from its computation procedure. Almost all algorithm mainly focus on the neighboring pixels. In contrast, BM3D algorithm uses the global information to estimate the noisy pixel. The advantage of BM3D is that it does not need much effort to tune parameter but it can get good performance even with first trial.

**Approach and procedure**

The first step is to analyze the image with eye to decide the type and possible mixed noise that may be included in the image. The algorithm will be

**Results**

The possible result may be still obscure to some extent. The algorithm should be chosen.

**Discussion**

The

**Answers**

1. two type of noise is added to the image, impulse noise and uniform noise(Gaussian noise).

2. The impulse noise should be filtered firstly by median filter algorithm. If it is filtered the average filter firstly, the abnormal value will be distributed equally to all pixels in the window. Hence, the following median filter is useless. It can not detect the peak pixel in the window. The other type of filter for while noise should be used next.

3. The median filter is chosen to eliminate or alleviate the impulse noise.

# Appendix A

1. Compilation environment

Compilation environment is Visual Studio 2019

1. Coding IDE

IDE is also Visual Studio 2019

1. Github code cloud store

The code is uploaded to the github of my repository for back-up

The github access link is <https://github.com/thetimeofblack/EE569-Digital-Signal-Processing.git> There are more temporary image and code in the repository.

# Reference and Bibliography

|  |  |
| --- | --- |
| [1] | .. Kostadin, 2007. []. Available: https://www.cs.tut.fi/~foi/GCF-BM3D/BM3D\_TIP\_2007.pdf. |
| [2] | Y. Mäkinen.etc, “Image and video denoising by sparse 3D transform-domain collaborative filtering,” 2007. []. Available: http://www.cs.tut.fi/~foi/GCF-BM3D/. |