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Image Denoising by Comprehensive Median Filter

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Abstract- Image denoising (or filtering) is a serious enhancement issue in the field of image processing. Many algorithms have been developed for denoising images and each algorithm has its advantages and disadvantages. Image is prone to different types of noise during image transmission or acquisition. The noise could be: speckle, Gaussian, salt and pepper; and each could be eliminated or minimized by special type of filters. In this paper, a non-linear filtering algorithm is proposed to minimize or eliminate the Salt and Pepper noise which causes white and black spots on the original image. It is called Comprehensive Median Filter (CMF), because it uses a comprehensive technique to enhance the standard median filter. The experiments show that the CMF algorithm reconstructs a high quality image in comparison with the standard median filter in term of the mean square error (MSE) as a quality evaluation parameter.

Keywords: Image Processing, Image Denoising, Image Filtering, Median Filter, Salt & Pepper Noise.

1 Introduction

The digital image processing could be defined as the processing of the images using computer [10]. These images may be corrupted with noise during its acquisition and transmission and also due to blurring artifacts. Most of the applications need to be applied on the original images rather than the noisy ones [12]. Many types of noise could corrupt the images and several filtering techniques could be implemented to eliminate or reduce these noises. The implementation of the filtering algorithm based on the application and the type of noise found in the image. Salt & pepper, Speckle, and Gaussian are the mostly common noises that corrupt the images. In the literature, many numbers of filtering algorithms were proposed [17]. However, the mostly implemented and used techniques or algorithms are: Median, Wiener, and Average.

Image restoration attempts to remove the noises in the images while trying to preserve as much features as possible. One important issue should be considered when the degraded image is processed: While reconstructing the original image is that, balance between removing noise and preserving image features. Because the proposed algorithm in this paper is dealing with the Salt & Pepper noise, several related researches are discussed below.

W. Luo [18] mentioned that the salt and pepper noise mainly corrupts most of the digital images and makes them prone to be noisy, because it makes the pixels have either the minimum or maximum intensity value (0 or 255 if the used bit-depth is 8 bits). The classical median filter is used with the proposed one in order to eliminate or reduce the salt and pepper noise without maleficence the edges' features.

Singh et al., [2] proposed a projected median filter to eliminate highly degraded colored images with salt and pepper. The presentation of the enhanced median filter behaves efficiently even with low noise levels, while keeping the most details of the colored images. The performance of their technique is tested and examined in term of many of quality evaluation measures such as: Image Enhancement Factor, Peak signal to Noise Ratio, and Mean Square Error.

Nair et al. [7] evinced an enhanced decision-based technique for reconstruction of the color and gray-scale images that are strongly noisy by Salt and Pepper noise that effectively eliminates this noise type while perpetuating the edges and other details. Rather than the employing only one implemented pixel value, their technique employs manipulated all the neighboring values in order to achieve better results than a classical median filter. The mechanism of this technique depends on denoising only the corrupted pixel using the mean of the already manipulated pixel values or using the median technique for the neighboring pixels.

Raymond et al. [11] suggested an algorithm of two-phases to eliminate salt and pepper noise. They used an adaptive median filter at the first phase to determine the pixels that are most similar to the corrupted pixel. In the consecutive phase, the image is reconstructed by a specified technique which is implemented only on the chosen pixels as noise elected. Their reconstructed images state an important improvement in compare with the reconstructed by other only non-linear filters or adaptive techniques, in terms of noise reduction and edge preservation.

Priyanka Kamboj and Versha Rani [8] have examined several denoising algorithms and noises' types. Image reconstruction and noise removal are anticipated to enhance the image quality as qualitative measure. At other side, it enhances the performance factors as the quantitative measure via implementation of the analysis techniques on the image. Reconstruct the exact original image or to reconstruct it as much as possible is the main goal of image filtering. The type of noise degraded or added on the image will effect on how the noise will be removed or minimized. Many methods for reduction of noise and image enhancement have been considered.

2 Types of Image Noises and Filters

2.1 Types of Image Noise

Image noise is a type of error occurs with an image during capturing step that change the intensity value of the pixel which does not belong to the real scene. The existence of noise makes an image has a: snowy appearance, mottled, rough, or grainy shape. Different noise types could degrade an image as follows:

2.1.1. Gaussian Noise (or Amplifier Noise)

It can be classified as one of statistical noise types; and it is found along the signal or image row [12]. Gaussian noise is a main portion of image sensor errors called "read noise", it is caused by the image dark areas which is a constant noise level [13][16]. Gaussian distribution is defined as the function of probability density for Gaussian noise which equivalent to the normal distribution. The type of noise is represented as an additive white to concede additive white Gaussian noise. This kind of noise occurs as a result of electronic error, and can be removed by adaptive filter.

2.1.2. Salt and Pepper Noise (or Impulse Noise)

Model of impulse noise describe an exemplified shape for Salt & Pepper noise. These impulses are corrupting the gray-scale pixel values by replacing them to the minimum or maximum permissible value (The types of these impulses could be: positive or negative). This type of noise is very strong in comparison the image signal strength. For monochrome images with bit-depth equals to 8 bits, the maximum value is 255 and the minimum will be 0. If the function of probability density is followed to degrade the pixel, then Salt & Pepper noise is known for this specific model of impulse noise. The positive impulses represented as white spots (salt), while the negative impulses represented as black spots (pepper) in the image. Salt & Pepper noise degrades and contaminates an image and its signal using pithy and abrupt turmoil and it displays the noisy pixels (black and white) as arbitrary dispersed along the image. Impulse noise can happened during the image capturing process e.g. acquisition, formation, storage, and transmission, and as a result of that, the quality of image will be negatively affected [6], [14]. Salt-and-pepper noise can be removed by use linear and median filters.

2.1.3. Speckle Noise (or Multiplicative Noise)

It exists in degrades the quality of the active radar [4], medical ultrasound, optical coherence tomography images, and synthetic aperture radar. Speckle noise of the image pixel values is interference pattern, deterministic, and random; which is computed by multiplication random value. Speckle noise could be eliminated using adaptive and non-adaptive filters. However, the mean filter method is the best technique to remove speckle noise.

2.2. Types of Image Filters

The main goal of the procedures of image restoration is to suppress degradation of the image with the help of the knowledge about its nature. The image degradation could be attributed to the defects present in the optical lenses, prorated movement between the camera and object, turmoil in the atmosphere, scanning quality, or for any other reason. Restoring the original image (or the original image with minimum errors and deviations) from its degraded form is the final objective of the image restoration. Figure 1 shows the step of how the image is degraded, filtered, and restored.

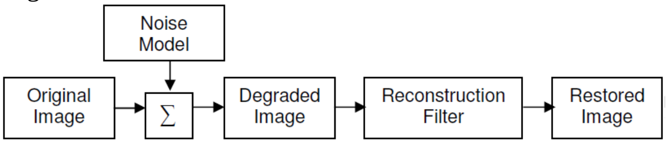

Fig.1. Work flow of Image Degradation and Restoration (Source: [3])

Filtering or denoising is a serious technique for enhancing image processing. Removing unwanted noise from an image is the main task of filtering. Filtering divide into two approaches linear and non-linear. Linear is fast but do not preserve the details, while non-linear preserve details. The best filtering algorithm have the ability to remove noise completely from image without losing the details. Noise removal, edge detection, sharpening, and smoothing are the main operations that can be achieved filtering in image processing field. Mainly, there are three types of filters:

3.2.1. Mean filter

Also called average linear filter [15], the mean filter compute the average of the specific corrupted block in the image, then the average value of the whole current block will be as the new value for the center pixel of that block, repeat this step until maintain the corruption pixels in the image by shifting the block over the image. This kind of filters is useful in smoothing the image, while it is useless and poor in edge preserving. The following is the steps for mean filter algorithm [1]:

- Place a window over pixels.
- Compute the average of all pixels under the current window.
- Replace the center pixel of the window by the average value.
- Repeat the above process for all corrupting image area.

3.2.2. Median filter

Median filter is classified as nonlinear filter; it is computing the median of the corruption block, then the median value will be the new value for the center pixel of the current block, repeat the step until maintain all the corruption image region [9], [5]. Median filter has advantages over the mean filter. The following is the steps for median filter algorithm [1]:

- Place a window over pixels.
- Sort the pixels value ascending or descending
- Compute the median
- The median value will be the new value of the center pixel of the window.
- Repeat the above process for all corrupting image area.

3.2.3. Wiener Filter

It is a type of an ideal linear filter, because it supplies linear estimation of a suitable sequence of signal from derived and affined with another sequence [16]. The estimation problem of stationary signals is resolved using Wiener filter. It also supplies effective results in denoising from the digital image, because it has distinct features and its statistical approach.

3 Comprehensive Median Filter: CMF (The Proposed Algorithm)

This section describes the proposed algorithm which is an enhanced version of the standard median filter (SMF). It is a very simple algorithm and it is called a Comprehensive Median Filter (CMF), because it considers the median of medians in all rows and the median of medians in all columns. The CMF denoise and filter the image using the following algorithm steps:

Begin

- For each pixel *f(x,y)* in input image *f*
  - Define a mask of the pixel value *f(x,y)* and its 8 neighbors: 3x3 mask
  - Define an array *MedianRowsArr* [Median (The First Row of Mask), Median (The Second Row of Mask), Median (The Third Row of Mask)]
  - Define an array *MedianColumnsArr* [Median (The First Column of Mask), Median (The Second Column of Mask), Median (The Third Column of Mask)]
  - *MedRowsElm*= Median (*MedianRowsArr*) // Median of the medians of all rows
  - *MedColsElm*= Median (*MedianColumnsArr*) // Median of the medians of all columns
  - *g(x,y)* = Median (*MedRowsElm*, *MedColsElm*, *f(x,y)*)

End

Note: the same steps will be followed when the mask is 5X5. However, it will be executed for 5 rows and 5 columns.

In order to explain how the CMF does work, consider the example in figure 1 which shows an image block 3X3 which is degraded/corrupted using salt and pepper noise. Note the intensity of the center pixel changed from 179 to 255 (255 is the White color). Then the degraded pixel is restored using the standard median filter and CMF. CMF restored the value of the center pixel to its original value (179). While the standard median filter restores a very close value to the original value (178). Thus there is a deviation using the standard filter will be greater than CMF which means the quality of restored pixel value using CMF will be better.

Appendix A

Fig. 2. A Comparison Example of Denoising using the Median and CMF algorithms

Denoising using Traditional Median Filter

At the right side of, the denoising process using the traditional median filter is achieved by sorting all the pixel values as follow: 10, 11, 12,13, 178, 179, 180, 180, and 255. The median value is 178 which will be set for the center of the block rather than the degraded value 255.

Denoising using CMF algorithm

At the left side of figure 1, CMF algorithm denoising the block by:

- Finding the median of each row and put them into array called *MedianRowsArr* as follow: 11, 178, and 179.
- Finding the median of each column and put them into array called *MedianColumnsArr*: 12, 180, and 179.
- Finding the median overall rows from Array *MedianRowsArr* and save it in the element called *MedianRowsElm*. The median value in array *MedianRowsArr* is 178.
- Finding the median overall rows from Array *MedianColumnsArr* and save it in the element called *MedianColsElm*. The median value in array *MedianRowsArr* is 178.

The new value for g(x,y) will be the median from f(x,y), MedianRowsElm, and MedianColsElm (i.e. the median from 178, 179, 255). So, the g(x,y) will be 179 rather than 255.

4 Experiments and Results

The performance of the CMF is compared with standard median filter using one of the performance evaluation metric such as Mean Square Error (MSE), which is equals to the square of difference between the corresponding pixels in the input and output images. The formula for MSE is given by the following equation:

$$MSE = \frac{1}{XY}\sum_{i=1}^{X}\sum_{j=1}^{Y}(f(x,y) - g(x,y))^2$$

Where g and f are the output and input images respectively. X and Y are the dimensions of the images (X is the number of rows, and Y is the number of columns). When the value of MSE is lower, then the quality of image will be better.

Five standard gray scale images (Lena, Cameraman, House, Barbara, and Boat) are prepared as test set images. These images have different sizes and types. The selection of these images came because they are the mostly tested images in image processing research area. Salt and Pepper noise with different levels is added to the test set images, the levels are: 1%, 5%, and 10% respectively. The Matlab built-in function imnoise is used to degrade the test set. The images are then reconstructed/denoise using the two filters: Standard Median filter and CMF algorithm. These algorithms were tested and implemented overall the test set images using Matlab R2010a.

Figure 3 shows the denoising process using 3X3 mask. The percentage of added noise to Lena image was 10%. It can be noticed that the filtered images using Standard Median Filter and CMF are very similar. Note that the quality of the filtered image using CMF is very high with preserving the image details and the sharpening of the edges.

Appendix B-1

Fig. 3. Comparative of Image Quality using 3X3 Mask (a) The original Image (b) Degraded Image 10% Noise (c) Image Denoising by Standard Median (d) Image Denoising by CMF.

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Figure 4 shows the denoising process under the same circumstances of the previous figure except that the mask is 5X5. CMF shows its ability to be efficient with different mask sizes. Note that because the mask size is enlarging, there is a little blurring in the edges with the two algorithms which is a normal issue.

Appendix B-2

Fig. 4. Comparative of Image Quality using 5X5 Mask (a) The original Image (b) Degraded Image 10% Noise (c) Image Denoising by Standard Median (d) Image Denoising by CMF

Generally, the filters are built to reduce the MSE between an original image and the available noisy or degraded image. So, the experiments were done to compare the two algorithms over the test set images in term of the MSE.

Table 1 shows the MSE values produced by the standard median and CMF at three noise levels: 1%, 5%, and 10%. Moreover, it shows that enhancement achieved by CMF. It is noticed that all the MSE values produced by CMF are less than the MSE values by the standard median, which means that the quality of the reconstructed images by CMF are better at all noise levels.

Appendix C-1

TABLE. 1. MSE for Standard Median and CMF at three Noise Levels: 1%, 5%, and 10% respectively (Mask: 3X3).

In table 1, columns: 4, 7 and 10 respectively show the enhancement percentage achieved by CMF over the standard median. These percentages are calculated using the following formula:

$$Enhancement\ by\ CMF = \frac{MSE\ using\ Median - MSE\ using\ CMF}{MSE\ using\ Median}\ \%$$

As example form table 1, for Lena image with noise level 1%, MSE using standard median was 1.2331, and MSE using CMF was 0.9283. So, the enhancement achieved by CMF will be computed as follows:

$$Enhancement\ by\ CMF = \frac{1.2331 - 0.9283}{1.2331}\ \% = 24.7\%$$

CMF gives better quality of reconstructed images as a general comment from the previous table. It enhances the quality from 14.4% (House image at 1% noise level) to 27.7% (Lena image at 10% noise level). The averages of MSE enhancement were: 18.8%, 18.2%, and 20.5% for all noise levels.

Figure 5 is a graphical representation for the MSE values from table 1. It obvious that CMF achieved better quality images by minimizing the MSE at all noise levels and for all images. (Note: In all charts, X coordinate is MSE value, Y coordinate is the image reference (Lena is I1, Cameraman is I2, and so on…)).

Appendix C-2

Fig. 5. Comparison between MSE by Standard Median and CMF with Mask 3X3 via different Noise Levels: 1%, 5%, and 10% respectively from left to right

In order to ensure that CMF works in all situations, it was tested and compared to standard median using 5X5 mask. Table 2 shows that MSE values using CMF are better, as well.

Appendix D-1

TABLE. 2. MSE produced by Traditional Median and CMF at three Noise Levels 1%, 5%, and 10% respectively (Mask: 5X5).

From table 2, the enhancement percentage achieved by CMF was from 12.6% (Barbara image at 1% noise level) to 22.6% (Lena image at 5% noise level). The averages of MSE enhancement were: 17.08%, 17.3%, and 17.0% for all noise levels.

Figure 6 is a graphical representation for the MSE values from table 2. Once again, CMF achieved better quality images by minimizing the MSE at all noise levels and for all images even the mask of 5X5. (Note: In all charts, X coordinate is MSE value, Y coordinate is the image reference (Lena is I1, Cameraman is I2, and so on…)).

Appendix D-2

Fig. 6. Comparison between MSE by Traditional Median and CMF with Mask 5X5 via different Noise Levels: 1%, 5%, and 10% respectively from left to right

5 Conclusions

Generally, image denoising is a critical task in the image processing field. The proposed algorithm in this paper attempts to filter and denoise the images from the salt and pepper noise. The proposed algorithm is called Comprehensive Median Filter, because it takes the median along all the rows and columns for degraded area. The CMF gives better image quality over the standard median filter in term of MSE parameter. Moreover, when the mask size is smaller (i.e. 3X3), then the quality of the filter image will be better. The only limitation with CMF is that it is mainly hard and expensive to compute.

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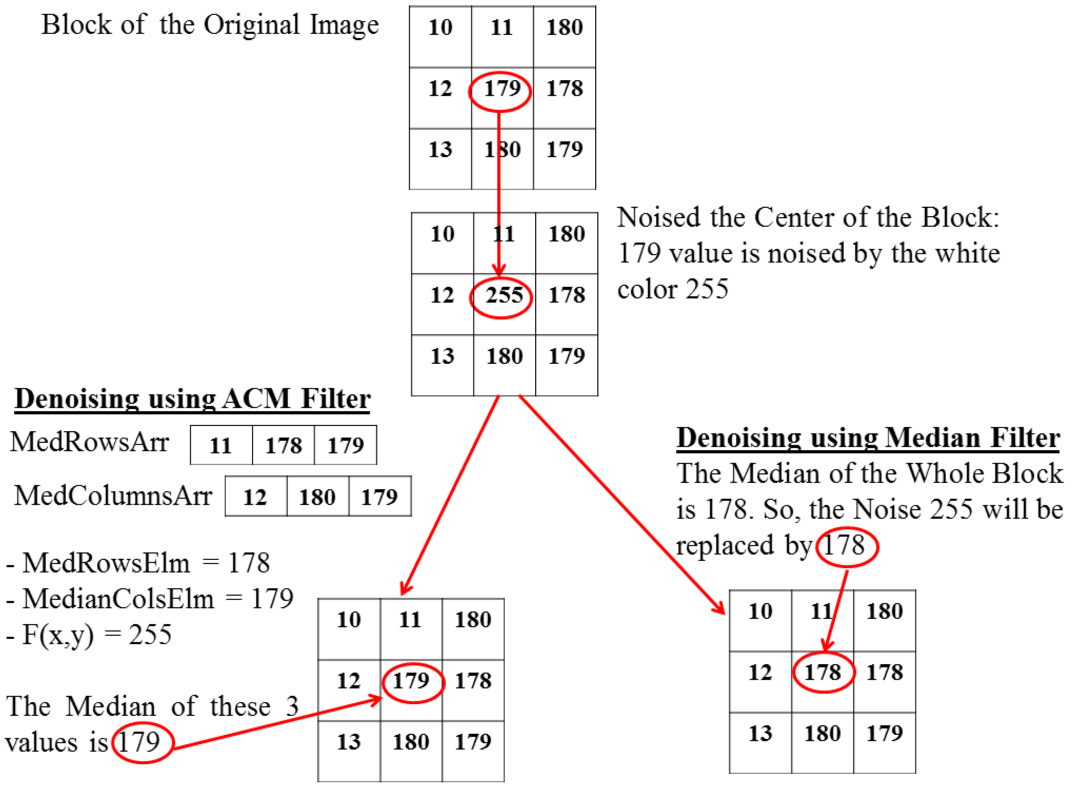
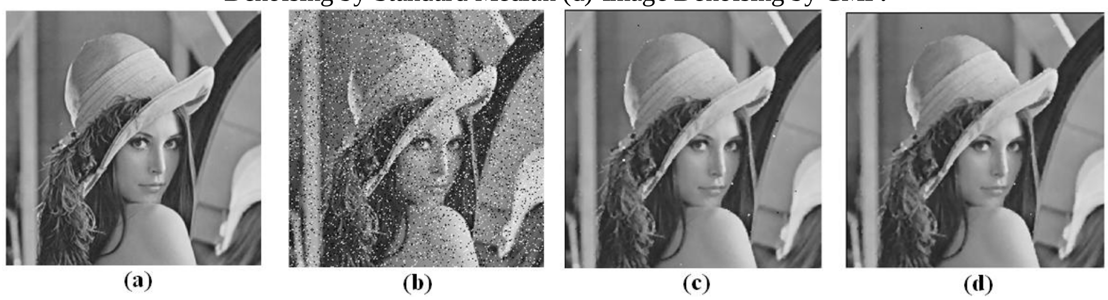
Appendix A

Fig. 2. A Comparison Example of Denoising using the Median and CMF algorithms



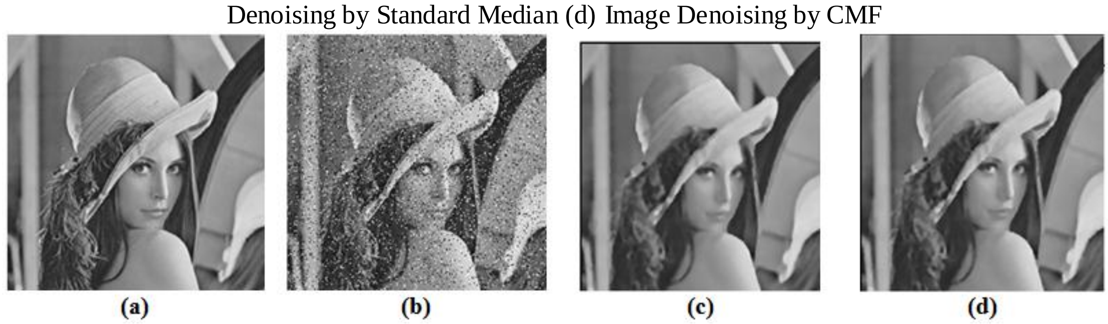
Appendix B-1

Fig. 3. Comparative of Image Quality using 3X3 Mask (a) The original Image (b) Degraded Image 10% Noise (c) Image Denoising by Standard Median (d) Image Denoising by CMF.



Appendix B-2

Fig. 4. Comparative of Image Quality using 5X5 Mask (a) The original Image (b) Degraded Image 10% Noise (c) Image Denoising by Standard Median (d) Image Denoising by CMF



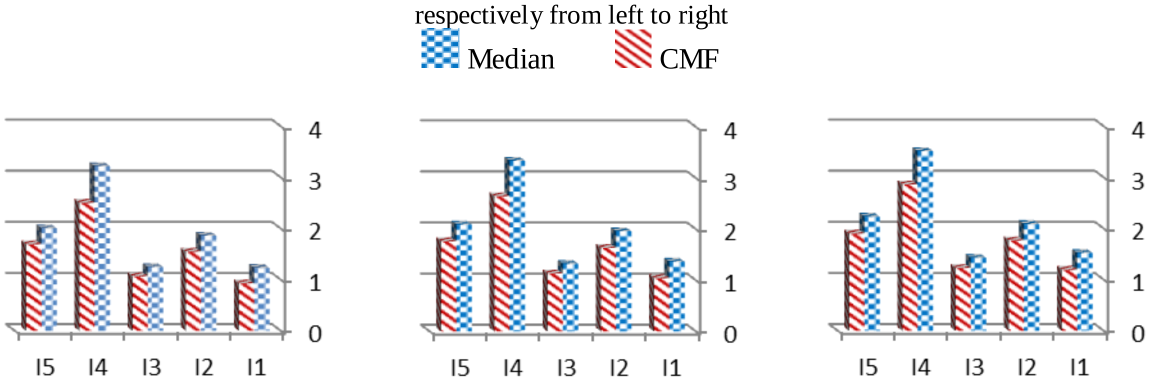
Appendix C-1

TABLE. 1. MSE for Standard Median and CMF at three Noise Levels: 1%, 5%, and 10% respectively (Mask: 3X3).

IMAGE	NOISE LEVEL 1%			NOISE LEVEL 5%			NOISE LEVEL 10%		
	MSE MEDIAN	MSE CMF	Enhancement Percentage by CMF	MSE MEDIAN	MSE CMF	Enhancement Percentage by CMF	MSE MEDIAN	MSE CMF	Enhancement Percentage by CMF
Lena	1.2331	0.9283	24.7%	1.3656	1.0452	23.5%	1.5258	1.1949	27.7%
Cameraman	1.8619	1.5486	16.8%	1.9625	1.6351	16.7%	2.0898	1.7689	18.1%
House	1.2483	1.0688	14.4%	1.3252	1.1338	14.4%	1.429	1.2286	16.3%
Barbara	3.2224	2.5034	22.3%	3.3409	2.6469	20.8%	3.5164	2.8649	22.7%
Boat	2.008	1.6947	15.6%	2.0944	1.7648	15.7%	2.2341	1.9023	17.4%
	Average		18.8%	Average		18.2%	Average		20.5%

Appendix C-2

Fig. 5. Comparison between MSE by Standard Median and CMF with Mask 3X3 via different Noise Levels: 1%, 5%, and 10% respectively from left to right



Appendix D-1

TABLE. 2. MSE produced by Traditional Median and CMF at three Noise Levels 1%, 5%, and 10% respectively (Mask: 5X5).

IMAGE	NOISE LEVEL 1%			NOISE LEVEL 5%			NOISE LEVEL 10%		
	MSE MEDIAN	MSE CMF	Enhancement Percentage by CMF	MSE MEDIAN	MSE CMF	Enhancement Percentage by CMF	MSE MEDIAN	MSE CMF	Enhancement Percentage by CMF
Lena	2.2071	1.7224	22.0%	2.3497	1.8184	22.6%	2.4012	1.8857	21.5%
Cameraman	2.8176	2.3661	16.0%	2.9056	2.4411	16.0%	2.9847	2.5067	16.0%
House	1.7375	1.4206	18.2%	1.7922	1.4582	18.6%	1.8437	1.5099	18.1%
Barbara	4.6234	4.0429	12.6%	4.6673	4.0728	12.7%	4.7252	4.1255	12.7%
Boat	3.092	2.5775	16.6%	3.0965	2.5803	16.7%	3.2142	2.6775	16.7%
	Average		17.08%	Average		17.3%	Average		17.0%

Appendix D-2

Fig. 6. Comparison between MSE by Traditional Median and CMF with Mask 5X5 via different Noise Levels: 1%, 5%, and 10% respectively from left to right