Noise Reduction of an Image and Performance Analysis of Different Denoising Techniques for Gray-Level Images

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Abstract- *In this paper, four different types of denoising algorithms are compared to reconstruct the original image from the noisy image. The methods are Vectorial Total Variation (VTV), Non-Local Means (NLM) algorithm, Block Matching and 2D Filtering (BM2D), Block Matching and 3D Filtering (BM3D). Chambolle's projection algorithm is used in VTV method, NLM algorithm is used in NLM method. In BM2D method 2D affine transformation, wiener filtering and soft thresholding is used to denoise the image. In BM3D method 3D affine transformation, soft thresholding and wiener filtering is used to denoise the image. The performance of these methods are evaluated by calculating the parameters such as PSNR (Peak Signal to Noise Ratio), MSE (Mean Square Error), SSIM(Structural Similarity index Metrics)and Elapsed time.*

Keywords- BM2D, BM3D, Gaussian noise, NLM, VTV.

I. INTRODUCTION

The main objective of image denoising is to improve the quality of an image. Various methods are proposed to remove the noise. Different filters are also used to denoise the image. By using the Median filter, fine details of the test image will not be preserved. Some details of an image are lost by using Gaussian filter [2]. Curvelet transform obtains small Mean Square Error [7]. But, it does not contain quantity of disturbing artifacts. Then Higher Order Singular Value Decomposition method preserves the fine textures. But conceptually more complex [8]. In recent years different denoising algorithm has appeared. Vectorial Total Variation [5], Non-Local Means algorithm [3] and BM3D[4] are the preferable methods for improving the quality of an image.

II. PROPOSED METHODOLOGY

In this paper four different types of image denoising algorithms are used to denoise the image. These methods improve the quality of an image.

A. VTV Method

Vectorial Total Variation is the image deniosing method. In this method, chambolle's projection algorithm is used to denoise the image.

Steps

- Input image is the gray scale image.
- Gaussian noise is added with an input image. This image is called as noisy image.
- Both input image and noise image is added together.
- Chambolle's projection algorithm is applied to the noisy image.
- Denoised image is produced after applying chambolle's projection algorithm.

B.NLM Method

Non-Local Means (NLM) is the image deniosing method. In this method, Non-Local Means algorithm is used to denoise the image.

Steps

- Input image is the gray scale image.
- Gaussian noise is added with an input image. This image is called as noisy image.
- Both input image and noise image is added together.
- Non-Local Means algorithm is applied to the noisy image.
- Denoised image is produced after applying Non-Local Means algorithm.

C.BM2D Method

Block Matching and 2D Filtering is the image denoising method. In BM2D technique, the input noisy image is processed by extracting the reference block from the noisy image. Every blocks are compared with reference block and similar blocks are grouped together in a 2D array. To locate the same blocks, distance between noisy blocks and reference

blocks are calculated. If the distance is less than the threshold value pixels are brought to the group.

Steps

- Input image is the noisy image.
- Noisy image is divided into blocks.
- Distance between noisy block and reference blocks are calculated.
- Similar blocks are stored in a 2D array.
- Two dimensional affine transformation is applied to 2D array.
- Wiener filtering is applied to the transformed image.
- Inverse affine transformation is performed.
- Denoised image is produced after applying inverse affine transformation.

D.BM3D Method

In BM3D technique, the input noisy image is processed by extracting the reference block from the noisy image. Every blocks are compared with reference block and similar blocks are grouped together in a 3D array. To locate the same blocks, distance between noisy blocks and reference blocks are calculated. If the distance is less than the threshold value pixels are brought to the group.

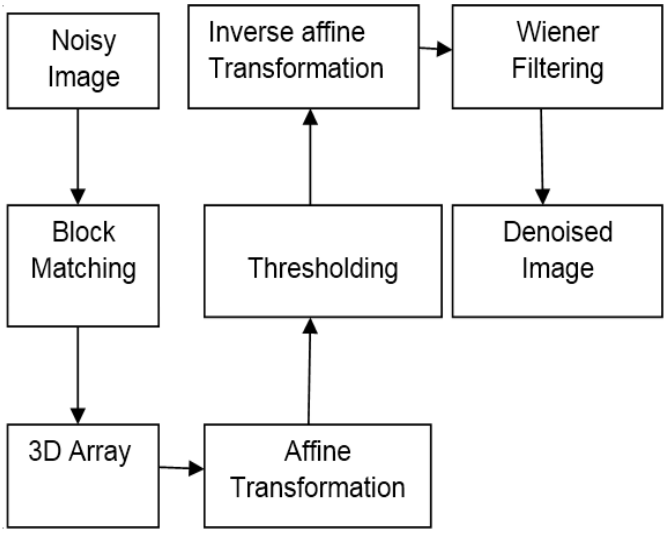

Figure 1. Block diagram of BM3D Method

Distance can be calculated by using the following formula [16].

$$d(Z_{XR}, Z_X) = \frac{\left\| \gamma'\left(T_{2D}^{ht}(Z_{XR})\right) - \gamma'\left(T_{3D}^{ht}(Z_X)\right) \right\|^2}{\left(N_1^{ht}\right)^2}$$

Where,

γ' – Threholding operator

T_{3D}^{ht} – Normalized 3D linear transform

N_1^{ht} – Block size

Z_{XR} – Reference Block

Z_X – Noisy Block

Similar blocks are grouped in a 3D array. Then 3D affine transformation is carried out for the 3D array. Some of the affine transformations are translation, scaling, rotation similarity transformation and shear mapping. In this paper translation method is used. Translation matrix can be written as,

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ t_x & t_y & t_z & 1 \end{bmatrix}$$

$t_x \rightarrow$ Displacement along x axis

$t_y \rightarrow$ Displacement along y axis

$t_z \rightarrow$ Displacement along z axis

Thresholding is applied to the transformed image. Then, inverse affine transformation is carried out to the filtered image. Wiener filtering is applied to the transformed array. The objective of wiener filter is to filter out the noise from the corrupted image and additionally to minimize the Mean Square Error (MSE).

III. PARAMETER MEASURES

The performance of different denoising methods are compared using three parameters such as mean square error, peak signal to noise ratio, Structural Similarity Index Metrics.

A. Mean Square Error

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\left[I(i,j) - \hat{I}(i,j)\right]^2$$

Where,

$I(i,j)$ – Reconstructed Image.

$\hat{I}(i,j)$ – Original Image.

m - Number of rows in an image.

n - Number of columns in an image.

B. Peak Signal to Noise Ratio

$$PSNR = 10\log_{10}\left(\frac{255^2}{MSE}\right)$$

C. Structural Similarity Index Metrics

SSIM is used to measure the image quality SSIM is a decimal value. It must be between -1 and 1. SSIM(Structural Similarity Index Metrics) is measured based on reconstructd image and input image.

$$ssim(x,y) = \left(\frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)}\right)$$

Where,

$\mu_x \rightarrow$ average of x

$\mu_y \rightarrow$ average of y

$\sigma_x^2 \rightarrow$ Variance of x

$\sigma_y^2 \rightarrow$ Variance of y

$\sigma_{xy} \rightarrow$ Covariance of x and y

$C_1 = (k_1 L)^2$

$C_2 = (k_2 L)^2$

$L \rightarrow$ Dynamic Range

IV. RESULTS AND DISCUSSIONS

A. Results for VTV Method

Vectorial Total Variation is used to reduce the total variation of an image and removes the unwanted details while preserving the edges at low Signal to Noise Ratio (SNR). It is also used to regularizing the image without smoothing the boundaries of the objects.

Figure 2.

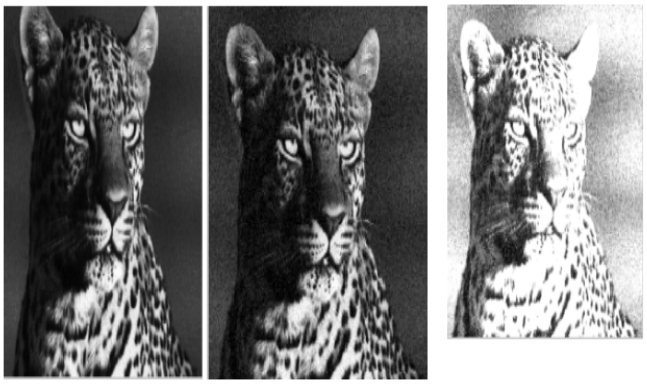

Figure 3.

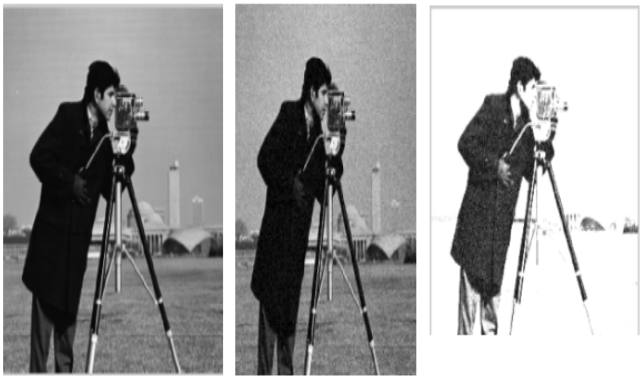

Figure 4.

The above Figure 2, Figure 3, Figure 4 is an examples of VTV denoising method. Figure 2(a), Figure 3(a), Figure 4(a) shows the original input image which is the gray-scale image. The size of the image is 256×256.The above Figure 2(b), Figure 3(b), Figure 4(b) shows the noisy image. Noisy image is generated by adding Gaussian noise with the original image.The above Figure 2(c), Figure 3(c), Figure 4(c) shows the denoised image.

B. Results for NLM Method

Non-Local Means algorithm take mean value of group of pixels surrounding the target pixel to smooth the image. This method loss very less details.

Figure 5.

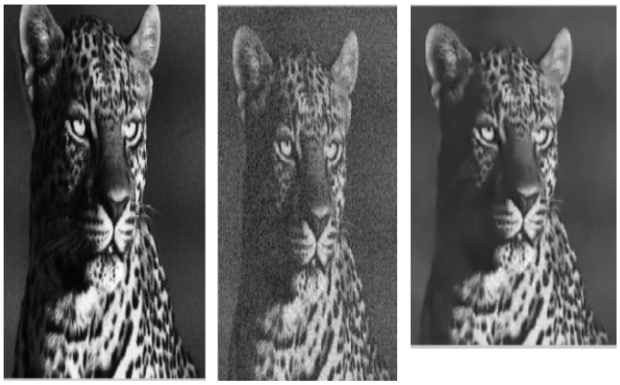

Figure 6.

Figure 7.

The above Figure 5, Figure 6, Figure 7 is an examples of NLM denoising method. Figure 5(a), Figure 6(a), Figure 7(a) shows the original input image which is the gray-scale image. The size of the image is 256×256.The above Figure 5(b), Figure 6(b), Figure 7(b) shows the noisy image. Noisy image is generated by adding Gaussian noise with the original image.The above Figure 5(c), Figure 6(c), Figure 7(c) shows the denoised image.

C. Results for BM2D Method

In Block Matching and 2D Filtering affine transformation is used. Affine transformation preserves points, straight lines and planes. In BM2D method 2D array is used to store the similar blocks.

Figure 8.

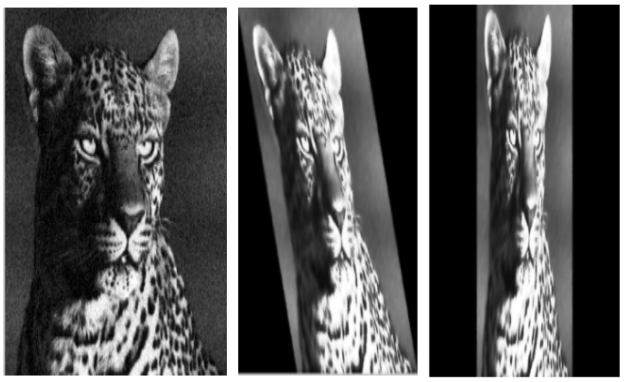

Figure 9.

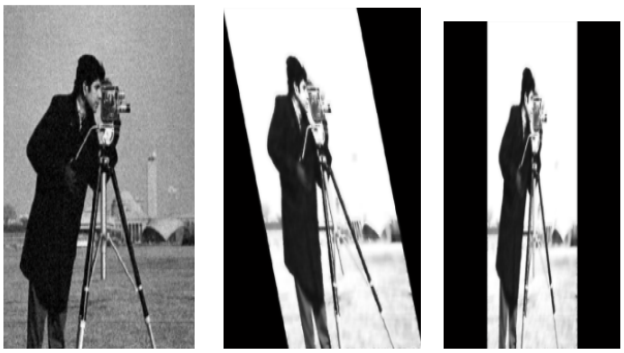

Figure 10.

The above Figure 8, Figure 9, Figure 10 is an examples of BM2D denoising method. Figure 8(a), Figure 9(a), Figure 10(a) shows the original input image which is the gray-scale image. The size of the image is 256×256.The above Figure 8(b), Figure 9(b), Figure 10(b) shows the noisy image. Noisy image is generated by adding Gaussian noise with the

original image.The above Figure 8(c), Figure 9(c), Figure 10(c) shows the denoised image.

D. Results for BM3D Method

In Block Matching and 3D Filtering affine transformation is used. Affine transformation preserves points, straight lines and planes. In BM3D method 3D array is used to store the similar blocks.

Figure 11.

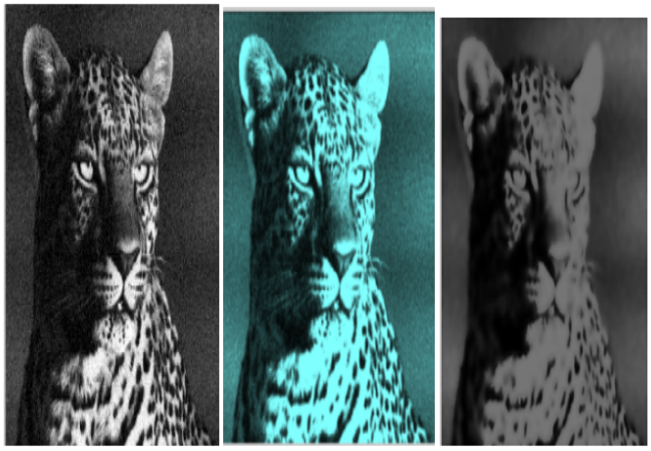

Figure 12.

Figure 13.

The above Figure 11, Figure 12, Figure 13 is an examples of BM2D denoising method. Figure 11(a), Figure 12(a), Figure 13(a) shows the original input image which is the gray-scale image. The size of the image is 256×256.The above Figure 11(b), Figure 12(b), Figure 13(b) shows the noisy image. Noisy image is generated by adding Gaussian noise with the original image.The above Figure 11(c), Figure 12(c), Figure 13(c) shows the denoised image.

V. PERFORMANCE ANALYSIS

The performance of denoised image is evaluated by calculating PSNR, MSE, SSIM and Elapsed time. The performance of proposed method are compared with the previous methods. From the performance comparision table it is inferred that Block Matching and 3D Filtering has high PSNR (Peak Signal to Noise Ratio) value and low MSE (Mean Square Error) value.

Table 1. Performance Comparision

Methods	Figure	PSNR	MSE	TIME	SSIM
Block Matching and 3D Filtering	**1**	**50.0353**	**0.6501**	**2.921**	**2.6436e-012**
	2	**45.0142**	**2.0657**	**3.155247**	**3.1574e-012**
	3	**43.7502**	**2.7635**	**2.878440**	**6.5469e-013**
Block Matching and 2D Filtering	1	30.6487	56.4431	3.737	2.8050e-12
	2	29.7163	69.9604	3.414843	2.3666e-012
	3	32.5009	36.8456	3.380728	4.8052e-013
Non-Local Means	1	30.075	63.910	21.266	1.7469e-015
	2	26.7766	136.590	19.93843	4.8886e-011
	3	28.3941	94.1157	19.42266	1.4721e-017
Vectorial Total Variation	1	24.4289	236.369	1.313	1.6342e-012
	2	24.9924	207.607	1.708609	2.6718e-012
	3	28.5433	91.6538	1.459518	5.2230e-013

VI. CONCLUSION

Four types of image denoising algorithm developed in this paper to improve the peak signal to noise ratio and to properly recover the image details. Thus, image denoising was done for testing an image using VTV, NLM, BM2D and BM3D methods. The performance of denoised image is evaluated by PSNR, MSE values, SSIM and Elapsed time. The performance of proposed method is better when compared

with the previous methods. Block Matching and 3D filtering has high peak signal to noise ratio and low mean square error.

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