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A Comparative Analysis of Impulse Noise Removal Techniques on Gray Scale Images

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Abstract

Various kinds of images and pictures are required as sources of information for analysis and interpretation. When an image is converted from one form to another such as scanning, transmitting, digitizing, storing etc., degradation occurs to the output image. Hence, the output image needs to be enhanced in order to be better analyzed. Denoising is the one of the pre processing technique in digital image processing. This paper investigates the performance of four denoising methods for removing the High Density Impulse Noise. They are Adaptive Bilateral Filter (ABF), Fuzzy Peer Group Filter (FPGF), Switching Bilateral Filter (SBF), and Boundary Discriminative Noise Detection Filter (BDND).The performance of the above four filters is compared by using five performance metrics. They are Peak-Signal-to-Noise-Ratio, Mean Square Error and Root Mean Square Error. The Experimental results show that the BDND filter based denoising method performs well than the other three methods.

Keywords**:** *Impulse Noise, Enhancement, filters, PSNR, MSE, SSIM, MAE and MD*

1. Introduction

Image Enhancement is a low-level process, which involves reducing the Noise from images. Digital images are often corrupted by Noise during their acquisition and transmission [1]. In particular, most commonly known of Noise are called additive Gaussian Noise and Impulse Noise. The need for efficient image denoising methods has been grown with the massive production of digital images and movies of all kinds, often taken in poor conditions. In recent years, a new concept in edge-preserving de-noising was proposed by Tomasi and Manduchi [2]. Most filters for Gaussian Noise suppression are designed to take advantage of the zero-mean property of the Noise and try to suppress it by locally averaging pixel channel values. To approach this problem, many nonlinear methods has been recently proposed, for instance: the bilateral filter [2, 3], the anisotropic diffusion [4], the chromatic filter [5], or the soft switching methods in [6], which motivate other fuzzy methods as the fuzzy directional derivative filter [7], the fuzzy bilateral filter [8], the fuzzy Noise reduction method [9], or the fuzzy-switching filter [10].

Impulse Noise (Salt & Pepper Noise):-

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Salt and pepper noise is a form of noise usually seen on images. It uniquely represents itself as randomly occurring white and black pixels. An effective noise reduction approach for this type of noise involves the usage of a median filter or a contrast harmonic mean filter. Salt and pepper noise affects into images in situations where the image is transferred quickly. The aim of these methods is to detect edges and details by means of local statistics and smooth them less than the rest of the image to better preserve their sharpness. However, these methods commonly identify Impulses as details or edges to be preserved, and, therefore, they are not able to reduce that this present system evaluate the performance of the image denoising techniques namely Adaptive Bilateral Filter (ABF) [11]. Fuzzy Peer Group Filter (FPGF) [12] Switching Bilateral Filter (SBF) [13] and BDND filter [14].

This paper is organized as follows: Section II presents an Adaptive bilateral filter, Fuzzy peer group filter, switching bilateral filter, BDND filter of image denoising methods. The results of application of the schemes are presented in section III Section IV presents conclusion of this paper.

2. Algorithm

2.1. Adaptive Bilateral Filter [11]

The response at [m0, n0] of the proposed shift-variant ABF to an impulse at [m, n] is given shown at the bottom of the page, where [m0, n0] and Ωm0, n0 are defined as before, and the normalization factor is given by

$$\gamma_{m0,n0} = \sum_{m=m0-N}^{m0+N} \sum_{n=n0-N}^{n0+N} \exp\left(\frac{(m-m0)^2+(n-n0)^2}{2\sigma^2}\right) \times \exp\left(\frac{\left((g[m,n]-g[m0,n0]-\zeta[m0,n0])^2\right)}{2\sigma^2[m0,n0]}\right) \quad \text{----------------- (1)}$$

The ABF [11] retains the general form of a bilateral filter, but contains two important modifications. First, an offset ζ is introduced to the range filter in the ABF. Second, both ζ and the width of the range filter σ_r in the ABF are locally adaptive. If ζ =0 and σ_r is fixed, the ABF will degenerate into a conventional bilateral filter. For the domain filter, a fixed low-pass Gaussian filter σ_r =1.0 with is adopted in the ABF. The combination of a locally adaptive ζ and σ_r transforms the bilateral filter into a much more powerful filter that is capable of both smoothing and sharpening. Moreover, it sharpens an image by increasing the slope of the edges. To understand how the ABF works, we need to understand the role of ζ and σ_r in the ABF.

2.2. Fuzzy Peer Group Filter [12]

This paper [12] uses a fuzzy similarity function, as the function above which, following the above terminology, is given by

$$\rho(F_i F_j) = e^{-\frac{\|F_i - F_j\|}{F_{(i)}}} \text{,i,j = 0 ………… } n^2\text{-1} \quad \text{----------------- (2)}$$

Where $\|.\|$ denotes the Euclidean norm and $F_\sigma > 0$ is a parameter.

2.3. Switching Bilateral Filter [13]

A noise detector is used in the SBF [13] filter to determine whether or not the current pixel is corrupted. This decision is made using the features of sorted quadrant median vector (SQMV), which can show the property of the background and is more reliable than only one median value. We obtain the reference median for noise identification from SQMV. If the reference median is improper, it can lead to lost detection or over detection. The lost noisy pixels have a great negative effect on the results and the undesired filtering removes the details. When a current pixel is very different from the reference median, it is identified as an impulse noise. When the difference between the current pixel and reference median is not too much, it may be a Gaussian noise or a noise-free pixel. Because the image background can give four different SQM values, the reference median can be selected from SQMV. The decision making mechanism is realized by employing a reference median and two thresholds
The switching bilateral filter is defined by using the below formula

$$u_{i,j} = \frac{\sum_{S=-N}^{N}\sum_{t=-N}^{N} W_G(s,t) W_{SR}(s,t) x_{i+sj+t}}{\sum_{S=-N}^{N}\sum_{t=-N}^{N} W_G(s,t) W_{SR}(s,t)}$$

----------- (3)

Where

$$W_G(s,t) = \exp - \frac{(i-s)^2 + (j-t)^2}{2\sigma^2 S}$$

---------- (4)

$$W_{SR}(s,t) = \exp - \frac{(I - x_{i+s,j+t})}{2\sigma^2 R}$$

--------- (5)

2.4 BDND Filter [14]

If the pixel is considered as the impulsive noise it is cleared by using the improved BDND filter [14]. The Efficient BDND Filtering Algorithm is calculated as below:

$$F_{mn} = medidan\{B_{m-p,n-u} | (p,u) \varepsilon V \wedge B_{m-p,n-u} \varepsilon Z_c$$

$$V=\{(p,u)|-(V_Y-1)/2 \le (p,u) \le (V_Y - 1)/2\}$$ --------(6)

If the pixel is considered as the Gaussian noise it is cleared by using the dynamic non local mean filter [11]. The dynamic non local mean filter is calculated as below

$$\overline{G}(R_1,R_2) = S(R_1,R_2)R_2$$

$$U(R_1R_2) = \begin{cases} \frac{0(R_1)}{0(R_2)} & K1 \ne K2 \text{ and } |0(R_1)-0(R_2)| \\ 1 & \text{otherwise} \end{cases}$$ ------------(7)

3. Experiments & Results

3.1. Experimental Images:

The performance of the algorithm is evaluated on several real images shown in Figure 1.1. These pictures are the most widely used standard test images used for image retargeting algorithms. These are till in the industry standard for tests. It is a good test images. These images are used for many image processing researches.

(a) (b) (c) (d)

Figure 3.1.1. Experimental Images (a) Image of Barbra (b) Image of Sail Boat (c) Image of Lena (d) Image of Pepper

3.2. Performance Metrics:

To evaluate the performance of the denoising techniques several performance metrics are available. We use the Peak Signal-to-Noise Ratio, Mean Square Error and Structural Similarity Index Measure

1. Peak Signal-To-Noise-Ratio - Peak signal-to-noise ratio (PSNR) to evaluate the quality between the attacked image and the original image. The PSNR formula is defined as follows:

$$\text{PSNR}=10\text{x}\log_{10} \frac{255x255}{\frac{1}{HxW}\sum_{x=0}^{H-1}\sum_{Y=0}^{W-1}[f(x,y)-g(x,y)]^2} \quad \text{---------(8)}$$

where H and W are the height and width of the image, respectively; and f(x,y) and g(x,y) are the grey levels located at coordinate (x,y) of the original image and attacked image, respectively.

2. Mean Square Error:

The mean square error or MSE of an estimator is one of many ways to quantify the difference between an estimator and the true value of the quantity being estimated. As a loss function, MSE is called squared error loss.

$$\text{MSE} = \frac{\sum_{m=1}^{M}\sum_{n=1}^{N}[x(m,n)-x'(m,n)]^2}{M*N} \quad \text{--------(9)}$$

3. Structural similarity Index Measure

The Structural similarity Index Measure (SSIM) is a method for measuring the similarity between two images. The SSIM is given by,

$$\text{SSIM(x,y)} = \frac{(2\mu_x\mu_y + C_1)(2\mu_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_2)(\sigma_x^2 + \sigma_y^2 + C_2)} \quad \text{-------------(10)}$$

4. Mean Absolute Error

The mean absolute error (MAE) is a quantity used to measure how difference between the original image and the noise free image. The mean absolute error is given by

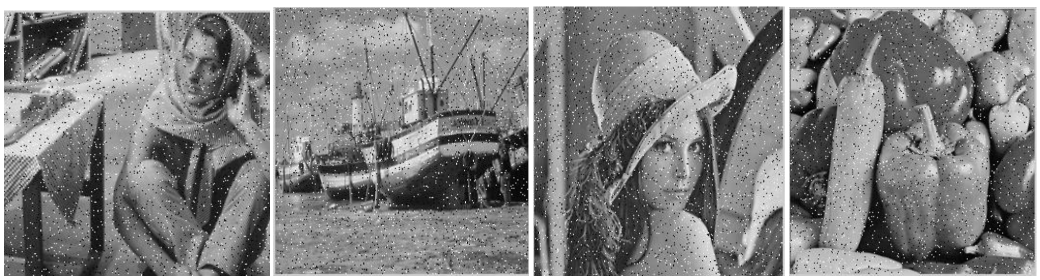
$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n}\left|f_i - y_i\right| \qquad \text{-----------(11)}$$

5. Max Difference Value

The max difference value (MD) is a quantity used to measure how difference between the original image and the noise free image. The MD is given by

$$\text{MD} = \max\left(\left|f_i - y_i\right|\right) \qquad \text{------------ (12)}$$

3.2.1. Experimental Results



(a) (b) (c) (d)

Figure 3.2.1.1. Impulse Noisy Images (a) Impulse Noisy Image of Barbara (b) Impulse Noisy Image of Sail Boat (c) Impulse Noisy Image of Lena (d) Impulse Noisy Image of Pepper

(a) (b) (c) (d)

Figure 3.2.1.2. Noise Free Images using BDND Filter (a) Noise Free image of Barbara (b) Noise Free Image of Sail Boat (c) Noise Free image of Lena (d) Noise Free Image of Pepper

3.3. Performance Analysis:

The performance analysis of Impulse noise table has been evaluated, the Impulse noise ratio sigma=5% to 50% iterations are evaluated for Barbara Image. Table 1 shows the performance of all techniques for Barbara Image.

Table 1. PERFORMANCE ANALYSIS OF Impulse Noise Table for Barbara Image

Filters	Metrics	Noise Ratio									
		5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
	PSNR	21.6532	20.1822	19.0592	18.1542	17.4276	16.7868	16.1618	15.7116	15.2508	14.8319

ABF	MSE	28.6132	29.9706	30.4160	31.5379	34.2894	36.9150	39.6688	41.7793	44.0557	46.2323
	SSIM	0.6067	0.6065	0.6051	0.6040	0.6029	0.6016	0.6005	0.5990	0.5977	0.5392
	MAE	21.4525	22.8162	24.3586	26.0988	27.9823	30.0157	32.3120	34.3631	35.0474	36.5766
	MD	235.1	235.3	235.8	236	239	240	243	243.7	244	244.2
FPGF	PSNR	24.4284	24.3876	23.952	23.8577	22.9830	22.2722	21.5743	21.0665	20.5412	20.0826
	MSE	26.1838	27.7351	28.6390	29.0840	32.1267	34.9083	37.8289	40.1341	42.6071	44.9168
	SSIM	0.7198	0.7196	0.7195	0.7099	0.7071	0.6357	0.6211	0.6092	0.6081	0.6020
	MAE	10.5884	10.6189	10.6243	10.6399	10.6650	10.6718	10.7032	10.7571	10.7962	10.8592
	MD	230	230.3	230.8	231	233.2	234.1	235	235.8	236	239
SBF	PSNR	22.4185	21.4616	21.4295	20.6293	20.0065	19.4286	18.9214	15.4215	15.0161	14.6487
	MSE	24.3004	27.1307	30.5538	33.5025	35.9928	38.4690	40.7820	43.1983	45.2620	47.2180
	SSIM	0.8621	0.8572	0.8260	0.8394	0.8276	0.7978	0.7831	0.7618	0.7297	0.6771
	MAE	12.8378	12.8780	12.9486	12.1024	12.1076	12.1176	12.1329	12.2012	12.4870	12.5103
	MD	233.9	234.3	235.8	235.23	236.2	237.8	238	239	241	243
BDND Filter	PSNR	32.3249	32.1528	31.0037	30.1956	30.4325	29.2674	29.8943	28.1822	27.7321	27.0340
	MSE	20.3024	21.1312	23.5531	23.2825	24.9128	25.4616	27.2820	28.1209	30.1621	32.1184
	SSIM	0.9189	0.9187	0.9071	0.9027	0.9012	0.8990	0.8993	0.8988	0.8984	0.8819
	MAE	8.2378	8.3780	8.4486	8.5284	8.5576	8.6009	8.6111	8.7123	8.8901	8.8988
	MD	226	226.4	225	224	224.8	225.2	227.4	228.1	229.3	230

The performance analysis of Impulse noise Table has been evaluated, the Impulse noise ratio sigma=5% to 50% iterations are evaluated for Sail Boat Image. Table 2 shows performance of all techniques for Sail Boat Image.

Table 2. PERFORMANCE ANALYSIS OF Impulse Noise Table for Sail Boat Image

Filters	Metrics	Noise Ratio									
		5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
ABF	PSNR	22.6531	22.5832	22.1592	21.9541	21.7674	20.7828	20.1618	19.3210	18.2410	18.1018
	MSE	27.6132	28.9706	29.4160	30.5399	31.2104	32.9150	33.6988	34.7793	36.0598	37.2301
	SSIM	0.5067	0.5065	0.5051	0.5040	0.5029	0.5016	0.4915	0.4890	0.4877	0.4392
	MAE	23.4525	23.8162	23.3586	23.0988	23.9823	26.0157	27.3120	28.3631	29.0474	31.5766
	MD	238	239	239.8	239.9	240	240.6	243	243.7	244	244.2
FPGF	PSNR	26.1284	25.7732	25.3521	24.8500	24.1230	24.4561	23.1987	23.1235	22.8712	22.0812
	MSE	28.1838	28.7351	28.6390	29.0840	29.1267	30.9083	30.8289	31.1341	32.6071	34.9988
	SSIM	0.8901	0.8896	0.888	0.887	0.8861	0.8851	0.8751	0.8662	0.8081	0.6020

				5	9						
	MAE	11.5884	11.6189	11.6243	11.6399	11.6650	11.6718	11.7032	11.7571	11.7962	11.8592
	MD	231	231.3	231.2	232	232.6	233.4	234	235.9	236.5	237
SBF	PSNR	23.4185	22.4612	22.4291	21.6232	21.0065	20.9286	19.1114	18.4211	17.0987	16.1287
	MSE	24.3304	27.9007	28.5538	30.8025	32.1201	33.1210	35.7120	37.1182	39.2630	40.2180
	SSIM	0.8910	0.8771	0.8663	0.8590	0.8475	0.8372	0.8231	0.7623	0.7298	0.6712
	MAE	12.8378	12.8780	12.9486	12.1024	12.1076	12.1176	12.1329	12.2012	12.4870	12.5103
	MD	230	231.4	232	233.1	234.8	235.2	237.4	238.1	239.3	240.9
BDND Filter	PSNR	31.3299	31.1587	31.0037	30.1956	29.9325	29.7074	29.6343	28.9922	27.7521	26.5523
	MSE	21.3024	21.1312	22.5531	22.3825	23.9128	24.5016	26.1209	28.1209	30.1623	32.7843
	SSIM	0.9189	0.9187	0.9071	0.9027	0.9012	0.8990	0.8993	0.8988	0.8984	0.8819
	MAE	7.2378	7.3780	7.4486	7.5248	7.5567	7.6015	7.6101	7.8023	7.8918	7.8912
	MD	225	225.4	226	226.3	226.8	227.2	227.4	227.9	228.3	229

The performance analysis of Impulse noise Table has been evaluated, the Impulse noise ratio sigma=5% to 50% iterations are evaluated for Lena Image. Table 3 shows performance of all techniques for Lena Image.

Table 3. PERFORMANCE ANALYSIS OF Impulse Noise Table for Lena Image

Filters	Metrics	Noise Ratio									
		5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
ABF	PSNR	23.6531	23.2822	22.6593	21.0549	21.3275	20.7112	19.1318	18.9111	18.6608	17.0019
	MSE	27.6139	27.9708	28.4167	29.5376	30.2895	31.9154	33.6683	34.7792	36.0550	38.2321
	SSIM	0.6967	0.8965	0.6751	0.6840	0.6429	0.6516	0.6905	0.5912	0.5910	0.5392
	MAE	22.4356	23.0987	23.2348	23.9876	24.3315	25.1178	26.6609	27.1123	28.6781	29.0912
	MD	235.1	235.3	235.8	236	239	240	243	243.7	244	244.2
FPGF	PSNR	24.4284	24.3876	23.952	23.8577	22.9830	22.2722	21.5743	21.0665	20.5412	20.0826
	MSE	26.1838	27.7351	28.6390	29.0840	32.1267	34.9083	37.8289	40.1341	42.6071	44.9168
	SSIM	0.7198	0.7196	0.7195	0.7099	0.7071	0.6357	0.6211	0.6092	0.6081	0.6020
	MAE	10.5884	10.6189	10.6243	10.6399	10.6650	10.6718	10.7032	10.7571	10.7962	10.8592
	MD	230	230.3	230.8	231	233.2	234.1	235	235.8	236	239
SBF	PSNR	25.9185	25.8616	25.6295	25.3293	25.1065	24.8286	23.6214	22.9215	21.3161	20.6587
	MSE	21.9210	21.6710	21.5538	22.9025	23.9921	24.4694	25.78001	26.1187	27.1387	29.0061
	SSIM	0.8120	0.8373	0.8571	0.8697	0.8476	0.8078	0.7831	0.7618	0.7297	0.6771
	MAE	11.8178	11.8280	11.9436	12.1424	12.1075	12.6176	12.8729	13.2012	13.3871	14.4456
	MD	233.9	234.3	235.8	235.23	236.2	237.8	238	239	241	243

BDND Filter	PSNR	32.3249	32.1528	31.0037	30.1956	30.4325	29.2674	29.8943	28.1822	27.7321	27.0340
	MSE	20.3024	21.1312	23.5531	23.2825	24.9128	25.4616	27.2820	28.1209	30.1621	32.1184
	SSIM	0.9189	0.9187	0.9071	0.9027	0.9012	0.8990	0.8993	0.8988	0.8984	0.8819
	MAE	8.2378	8.3780	8.4486	8.5284	8.5576	8.6009	8.6111	8.7123	8.8901	8.8988
	MD	226	226.4	225	224	224.8	225.2	227.4	228.1	229.3	230

The performance analysis of Impulse noise table has been evaluated, the Impulse noise ratio sigma=5% to 50% iterations are evaluated for Pepper Image. Table 4 shows performance of all techniques for Pepper Image.

Table 4. PERFORMANCE ANALYSIS OF Impulse Noise Table for Pepper Image

Filters	Metrics	Noise Ratio									
		5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
ABF	PSNR	22.9539	22.8831	22.7598	21.6542	21.5677	20.1823	20.2617	19.3214	18.4416	18.5058
	MSE	27.1132	28.2106	29.3460	30.6799	31.1004	32.6750	33.1988	34.6593	36.2298	37.1701
	SSIM	0.5167	0.5165	0.5151	0.5140	0.5129	0.5116	0.4215	0.4490	0.4677	0.4092
	MAE	23.1234	23.0912	23.5643	23.8756	23.1235	26.6753	27.1280	28.3456	29.2134	31.9871
	MD	238.5	239.2	239.8	239.9	240.3	240.6	241	242.7	243.2	244.1
FPGF	PSNR	26.1284	25.7732	25.3521	24.8500	24.1230	24.4561	23.1987	23.1235	22.8712	22.0812
	MSE	28.1838	28.7351	28.6390	29.0840	29.1267	30.9083	30.8289	31.1341	32.6071	34.9988
	SSIM	0.8901	0.8896	0.8885	0.8879	0.8861	0.8851	0.8751	0.8662	0.8081	0.6020
	MAE	10.5884	10.6189	10.6243	10.6399	10.6650	10.6718	10.7032	10.7571	10.7962	10.8592
	MD	230	230.3	230.8	231	233.2	234.1	235	235.8	236	239
SBF	PSNR	23.4185	22.4612	22.4291	21.6232	21.0065	20.9286	19.1114	18.4211	17.0987	16.1287
	MSE	24.3304	27.9007	28.5538	30.8025	32.1201	33.1210	35.7120	37.1182	39.2630	40.2180
	SSIM	0.8910	0.8771	0.8663	0.8590	0.8475	0.8372	0.8231	0.7623	0.7298	0.6712
	MAE	12.8371	12.8782	12.9489	12.1021	12.1036	12.1091	12.1331	12.2000	12.4210	12.5215
	MD	231	232.4	232.8	233.5	234.1	234.7	235.4	236.1	237.3	239
BDND Filter	PSNR	33.1149	33.1012	33.0031	32.9156	32.1291	31.4614	31.9946	30.9822	30.7321	29.0340
	MSE	19.3024	20.1312	20.5531	20.2825	20.9328	21.4646	21.2091	21.3410	22.1098	23.1110
	SSIM	0.9181	0.9182	0.9073	0.9024	0.9015	0.8999	0.8998	0.8987	0.8986	0.8815
	MAE	7.2318	7.3790	7.4286	7.5284	7.5536	7.6007	7.6141	7.7623	7.8501	7.8960
	MD	225	224.4	224	223	223.8	224.2	224.4	225.1	226.3	229

From the above Table 1-4 it is shown that the BDND filter method is considered as the best method for High Density Impulse Noise Removal Techniques for all standard Images. Because it has higher PSNR (see Table 1-4) and SSIM value with lower MSE.

4. Conclusion

In this paper, High Density Impulse noise detection and reduction techniques were implemented and the results were compared by using five performance parameters. They are Peak-Signal-to-Noise-Ratio, Mean Square Error and structural similarity index measure, Mean Absolute Error, and Maximum Difference. The experimental results show that the BDND denoising method performed well than the other methods.

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