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Analysis of Different Filter Techniques for Image Denoising

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ABSTRACT
Images are very important source in research field as it is easier to convey information through them. There are several resources available to generate high quality images, but presence of noise can degrade these images. Hence image denoising is one of the crucial preprocessing steps in digital image processing. This paper is an attempt to study the effect of different noise types on images and how efficiently denoising techniques can reduce noise. Gaussian noise, poisson noise, salt & pepper noise and speckle noises are the most commonly occurring noise types which are considered to conduct experiments with gray scale images. Denoising techniques applied here are gaussian filter, median filter, wiener filter, bilateral filter, non-local means and bm3d. Results of different noise used on gray scale images compared with the help of quantitative and qualitative performance parameters such as Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR) and Structural Similarity Index Measure (SSIM).

Keywords
Image Denoising, Filtering Technique, Spatial domain, Noise types, Bilateral, Nonlocal means, BM3D.

1. INTRODUCTION
Image distortion is one of the most important problems in image processing. In the case of digital images, image distortion due to various types of noise such as gaussian noise, poisson noise, speckle noise, salt and pepper noise, and many more are fundamental noise types. These noises could have been introduced by a noise source in the vicinity of image capturing devices, a faulty memory location, or an imperfection/inaccuracy in image capturing devices such as cameras, misaligned lenses, a short focal length, scattering, and other adverse conditions in the environment [1][2][17][18][19]. Therefore, selection of proper image denoising technique is very important.

Gaussian noise: It is one of the most common types of noise found in images, and it is also known as Additive White Gaussian Noise (AWGN) or normal noise. This type of noise is commonly added to an image during image acquisition, such as sensor noise caused by low light, high temperature, and transmission noise such as electronic circuit noise or amplifier noise [3].

Poisson noise: Poisson noise, also known as photon noise or shot noise, is a type of electronic noise. Such noise occurs when the number of photons sensed by the sensor is insufficient to provide detectable statistical information [4]. The statistical nature of electromagnetic waves such as x-rays, visible lights, and gamma rays causes the appearance of this noise [2].

Salt & pepper noise: An impulse noise or spike noise is another name for salt and pepper noise. It appears as a white and/or black image impulse and is caused by pixel malfunction in camera sensors, faulty memory locations in hardware, or transmission over a noisy channel [19]. White and black spots appear in grayscale images as a result of this type of noise. In other words, salt and pepper noise in an image result in dark pixels in bright regions and bright pixels in dark regions [20].

Speckle noise: It's noise with a multiplicative effect. It can be seen in coherent imaging systems such as laser, radar, and acoustics, among others [5][6][21].

2. MATERIALS AND METHODS
Comparative analysis is being carried out on several spatial domain filtering techniques to understand the effect of these denoising techniques on most commonly occurring noise types. The following block diagram in figure 1 depicts the procedure used to conduct the comprehensive study.

- Read all the input images of size 512X512.
- Gaussian, Poisson, Salt & pepper and Speckle noises are added to the input images.
- Denoise the images by applying various spatial filtering techniques such as gaussian, median, wiener, bilateral, nonlocal means and bm3d filters.
- Analyze the performance of different filtering methods in denoising images using the results of PSNR, MSE and SSIM values.

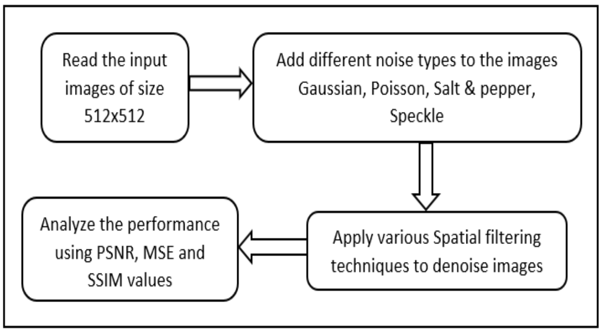


Fig 1: Block diagram of the proposed study

Details of filtering techniques considered to conduct experiments are given in the following table 1 along with their advantages and disadvantages.

Analysis of different filter techniques is given in the following table 1. Set of input images considered for experiment are collection of widely used gray scale images of size 512x512.

Table 1. Analysis of different filter techniques

Sl. No.	Filtering Technique	Filter Type	Advantages	Disadvantages
1	Gaussian [7] & Adaptive Gaussian filter [22]	Linear smoothing filter	One of the earliest and fast denoising Process.	Edges are either blurred or disappeared resulting in poor contrast. This technique is applicable only when noise variance is known.
2	Median filter [8][9][10][16]	Non-linear filter	Median filters are simple to use and has better edge preserving capabilities than linear filters	They tend to reform noisy pixels as well as clean pixels due to uniform application across the image.
3	Weiner filter [23]	linear filter	The Wiener filter removes additive noise while also inverting blurring. In terms of mean square error, it is optimal.	Wiener filters cannot reconstruct frequency components which have been degraded by noise.
4	Bilateral filter [24]	Non-linear filter	Simple, edge-preserving, non-iterative filter to speed up denoising process.	Bilateral filter introduces gradient reversal artefacts and gives poor performance at high noise intensity.
5	Non-local means [25][26]	Non-local averaging	The NLM filter employs weighted averages of similar patches in the image. It is very effective at removing noise.	Because of the non-locality, the method is very slow and has high computational complexity.
6	BM3D [11][12][13]	Non-locally collaborative filter	It combines the benefits of spatial and frequency filtering to achieve better denoising effect, which is a breakthrough in traditional denoising algorithms.	As noise levels rise, BM3D's denoising performance suffers significantly, and artefacts appear, particularly in flat areas.

3. ESTIMATION

Metrics used as performance parameters MSE, PSNR, SSIM are quantitative and qualitative measures to check the performance of image denoising methods [14]. In addition to the denoising effect, edge and texture preservation is important to the evaluation of the denoising method [15]. MSE is calculated using following eqn. (1) Where, I1=original image, I2=denoised image, m=height and n=width of the image.

$$MSE = \frac{\sum_{M,N}[I_1(m,n)-I_2(m,n)]^2}{M,N} \quad (1)$$

PSNR is calculated using following eqn. (2) R is the maximal variation in the input image data. If it has an 8-bit unsigned integer data type, R is 255.

$$PSNR = 10\log_{10}(\frac{R^2}{MSE}) \quad (2)$$

SSIM value is calculated using eqn. (3) where $\mu_x \mu_y$, σ_x, and σ_y are the means and variances of x and y, resp., σ_{xy} is the covariance between x and y, and C1 and C2 are constant values.

$$SSIM(x,y) = \frac{(2\mu_x\mu_y+c1)(2\sigma_{xy}+c2)}{(\mu_x^2+\mu_y^2+c1)(\sigma_x^2+\sigma_y^2+c2)} \quad (3)$$

4. RESULTS AND DISCUSSION

As per overall comprehensive analysis conducted on set of grey scale images of 512X512 resolution, following results are being noticed.

- BM3D filter gives good performance in removing gaussian noise.
- Bilateral and NLM filters gives good performance in removing for Poisson noise.
- Median filter gives good performance in removing salt & pepper noise.
- NLM and BM3D gives good performance in removing speckle noise.
- It is also noticed that bilateral filter is not performing well with gaussian, salt &pepper, speckle noises and median filter is giving poor results with poisson noise.

Following figure 2, figure 3 and figure 4 shows the graphs representing comparative analysis of PSNR, MSE and SSIM values after applying different filtering techniques in removing various noise types for Barbara image. These graphs clearly depict the results mentioned above. Figure 5 shows the visual comparisons of results on sample images corrupted by different noises. Similarly, table 2, table 3, table 4 and table 5 represents the numerical results obtained after applying filters on input images for removing gaussian noise, poisson noise, salt & pepper noise and speckle noise respectively. The values of PSNR, MSE and SSIM are used to state which filter is more suitable in removing particular noise and also to determine filters that are performing poor with a noise type.

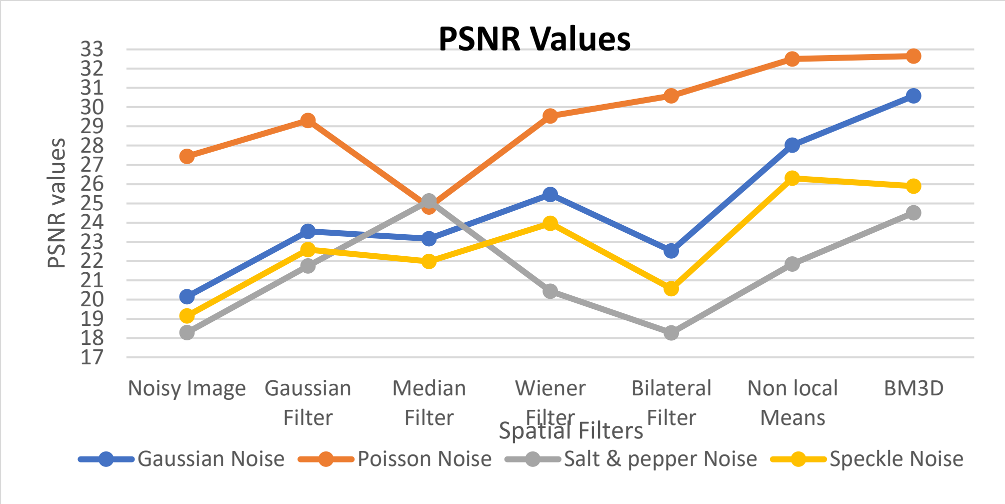


Fig 3: Comparison of PSNR values of different filtering techniques for Barbara image

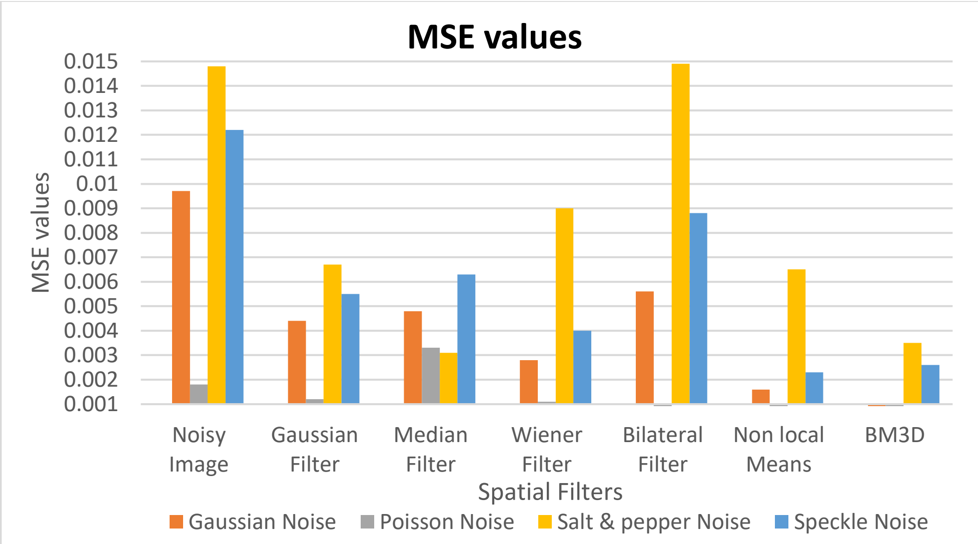


Fig 3: Comparison of MSE values of different filtering techniques for Barbara image

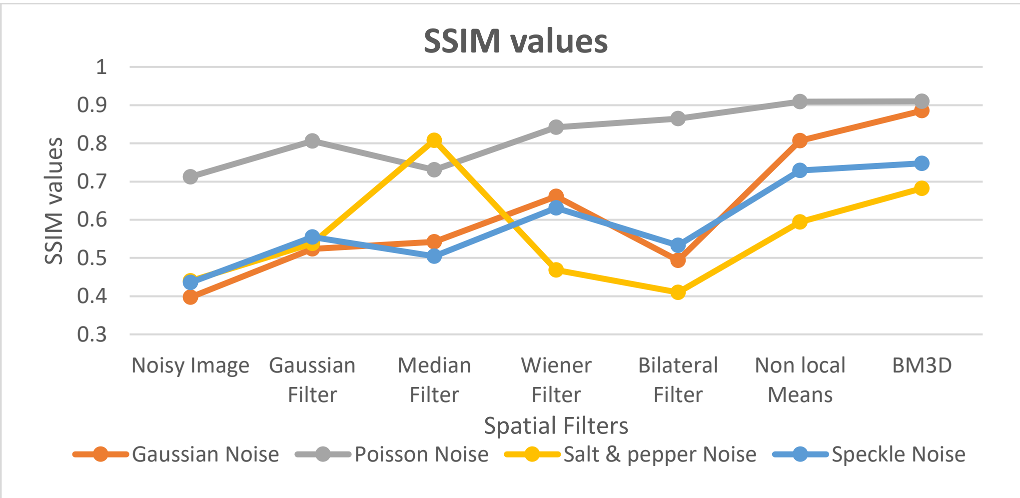
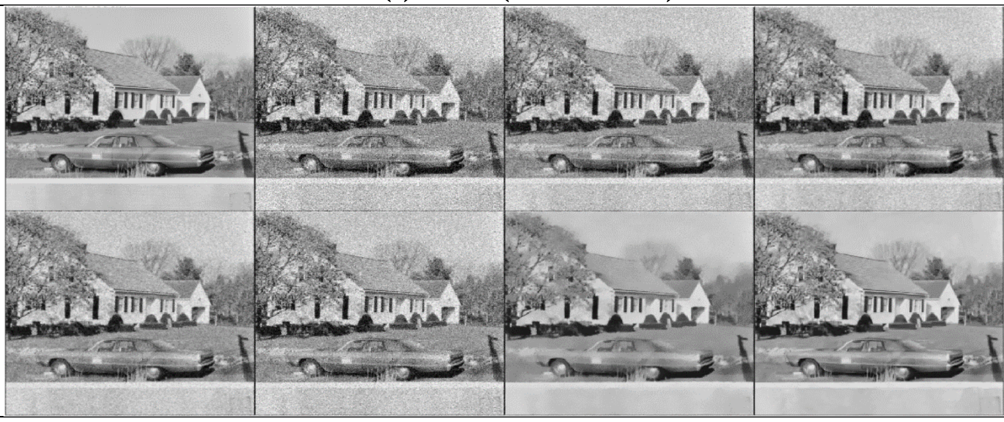


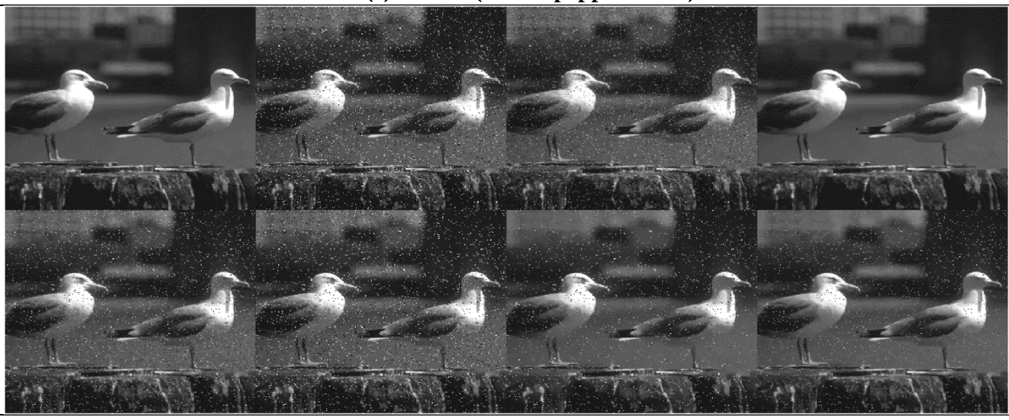
Fig 4: Comparison of SSIM values of different filtering techniques for Barbara image

(a) House (Gaussian Noise)



(b) Butterfly (Poisson Noise)

(c) Duck (Salt & pepper Noise)



(d) Boat (Speckle Noise)

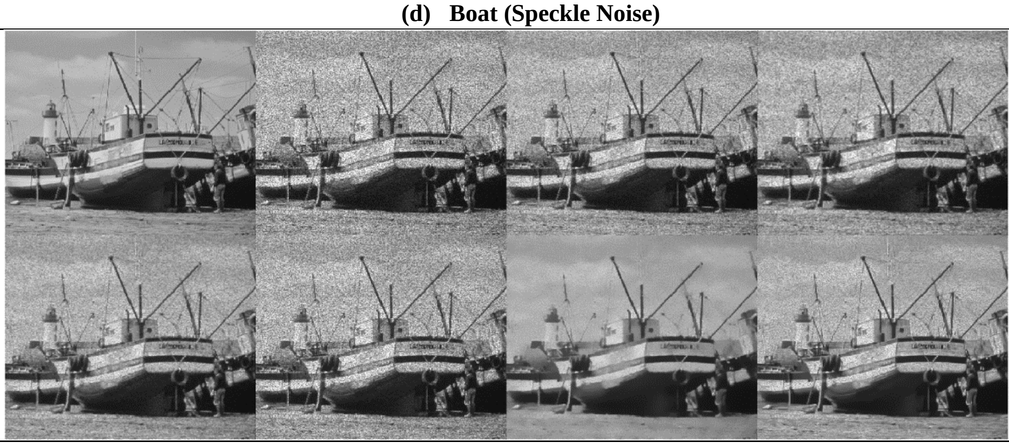


Fig 5: Visual comparisons of denoising results on (a) house (b) butterfly (c) duck (d) boat images corrupted by gaussian, poisson, salt & pepper and speckle noise respectively

Table 2. Results of applying filters on various images in removing gaussian noise

Gaussian Noise								
Images	**Performance Parameters**	**Noisy Image**	**Gaussian Filter**	**Median Filter**	**Wiener Filter**	**Bilateral Filter**	**Non local Means**	**BM3D**
Barbara	PSNR	20.1508	23.5466	23.1667	25.4644	22.5307	28.0174	30.5826
	MSE	0.0097	0.0044	0.0048	0.0028	0.0056	0.0016	0.0009
	SSIM	0.3972	0.5237	0.5417	0.6607	0.4936	0.807	0.8852
House	PSNR	20.1307	23.8274	25.8799	26.6871	22.7978	27.6994	29.5874
	MSE	0.0097	0.0041	0.0026	0.0021	0.0053	0.0017	0.0011
	SSIM	0.3576	0.4994	0.6124	0.6692	0.4638	0.7787	0.8555
Wheel	PSNR	21.0399	23.2471	20.7166	24.6207	23.4303	26.7724	27.8269
	MSE	0.0079	0.0047	0.0085	0.0035	0.0045	0.0021	0.0016
	SSIM	0.5161	0.6164	0.5956	0.7224	0.6324	0.8298	0.8521
Pillars	PSNR	20.0316	23.776	26.1309	26.6646	22.7665	27.9747	29.922
	MSE	0.0099	0.0042	0.0024	0.0022	0.0053	0.0016	0.001
	SSIM	0.3024	0.4495	0.561	0.6031	0.4101	0.7238	0.8068
Fish	PSNR	20.6868	23.8831	24.6044	25.2253	22.9449	25.5455	26.4104
	MSE	0.0085	0.0041	0.0035	0.003	0.0051	0.0028	0.0023
	SSIM	0.4457	0.5506	0.5803	0.5895	0.5241	0.5777	0.6117
Bird	PSNR	20.1329	23.6774	24.7335	25.8407	22.627	26.2397	27.7499
	MSE	0.0097	0.0043	0.0034	0.0026	0.0055	0.0024	0.0017
	SSIM	0.3922	0.5222	0.5873	0.6526	0.4885	0.7423	0.8188
Boat	PSNR	20.1361	23.8619	25.9579	26.7242	22.8565	28.4706	30.5271
	MSE	0.0097	0.0041	0.0025	0.0021	0.0052	0.0014	0.0009
	SSIM	0.3196	0.4585	0.5755	0.6274	0.4257	0.7819	0.8571
Cat	PSNR	20.8252	24.4499	26.2729	26.8193	23.735	28.1013	29.1809
	MSE	0.0083	0.0036	0.0024	0.0021	0.0042	0.0015	0.0012
	SSIM	0.3154	0.4715	0.5529	0.6414	0.4549	0.7435	0.7882
Duck	PSNR	20.3224	24.0713	26.8162	27.2808	23.3348	30.4844	32.2853
	MSE	0.0093	0.0039	0.0021	0.0019	0.0046	0.0009	0.0006
	SSIM	0.2232	0.3605	0.5223	0.5619	0.3399	0.8185	0.8741
Street	PSNR	20.1121	23.8375	25.9871	26.6495	22.8676	27.938	29.7707
	MSE	0.0097	0.0041	0.0025	0.0022	0.0052	0.0016	0.0011
	SSIM	0.3166	0.4715	0.5688	0.6202	0.433	0.6997	0.7744

Table 3. Results of applying filters on various images in removing poisson noise

Poisson Noise								
Images	**Performance Parameters**	**Noisy Image**	**Gaussian Filter**	**Median Filter**	**Wiener Filter**	**Bilateral Filter**	**Non local Means**	**BM3D**
Barbara	PSNR	27.4444	29.3109	24.8152	29.5337	30.5808	32.4959	32.6519
	MSE	0.0018	0.0012	0.0033	0.0011	0.0009	0.0006	0.0005
	SSIM	0.7125	0.8061	0.7306	0.8422	0.8649	0.9089	0.91
House	PSNR	26.1141	29.4398	29.2937	30.8469	30.799	31.7258	30.6376
	MSE	0.0024	0.0011	0.0012	0.0008	0.0008	0.0007	0.0009
	SSIM	0.6006	0.7309	0.7849	0.8362	0.8064	0.8833	0.8634
Wheel	PSNR	26.4129	26.5562	21.5251	27.333	29.9609	30.4426	29.1851
	MSE	0.0023	0.0022	0.007	0.0018	0.001	0.0009	0.0012
	SSIM	0.6987	0.776	0.7001	0.8035	0.848	0.8727	0.8563
Pillars	PSNR	27.9318	31.2514	30.4355	32.0413	32.554	32.6717	30.8008
	MSE	0.0016	0.0007	0.0009	0.0006	0.0006	0.0005	0.0008
	SSIM	0.6562	0.7775	0.785	0.8322	0.8438	0.8671	0.8152
Fish	PSNR	28.5405	30.6239	26.9827	29.3253	30.729	30.3386	27.7843
	MSE	0.0014	0.0009	0.002	0.0012	0.0008	0.0009	0.0017
	SSIM	0.8534	0.8913	0.7766	0.8333	0.888	0.8683	0.7595
Bird	PSNR	28.1484	30.459	27.4762	30.1028	31.1978	30.5017	28.3751
	MSE	0.0015	0.0009	0.0018	0.001	0.0008	0.0009	0.0015
	SSIM	0.7317	0.8294	0.7993	0.8598	0.8911	0.888	0.8225
Boat	PSNR	26.7476	30.1077	29.7138	31.491	31.5326	32.4712	31.7834
	MSE	0.0021	0.001	0.0011	0.0007	0.0007	0.0006	0.0007
	SSIM	0.6071	0.7392	0.785	0.8342	0.8212	0.885	0.8731
Cat	PSNR	29.9375	32.8846	30.759	32.4901	33.096	31.2562	30.0944
	MSE	0.001	0.0005	0.0008	0.0006	0.0005	0.0007	0.001
	SSIM	0.8111	0.8924	0.849	0.8915	0.9111	0.8885	0.7942
Duck	PSNR	29.7145	32.8997	32.7386	34.476	35.0291	34.5531	33.8105
	MSE	0.0011	0.0005	0.0005	0.0004	0.0003	0.0004	0.0004

	SSIM	0.6618	0.8014	0.8462	0.879	0.8944	0.9074	0.8898
Street	PSNR	27.6742	30.9143	29.8284	31.4852	32.0965	31.8281	30.694
	MSE	0.0017	0.0008	0.001	0.0007	0.0006	0.0007	0.0009
	SSIM	0.6834	0.7978	0.7719	0.8183	0.8419	0.8293	0.7832

Table 4. Results of applying filters on various images in removing salt & pepper noise

Salt & pepper Noise								
Images	**Performance Parameters**	**Noisy Image**	**Gaussian Filter**	**Median Filter**	**Wiener Filter**	**Bilateral Filter**	**Non local Means**	**BM3D**
Barbara	PSNR	18.2848	21.742	25.1211	20.4398	18.2748	21.847	24.5151
	MSE	0.0148	0.0067	0.0031	0.009	0.0149	0.0065	0.0035
	SSIM	0.44	0.5376	0.8081	0.4681	0.4097	0.5937	0.6817
House	PSNR	18.2157	21.8788	31.0137	20.6514	18.2362	20.4657	23.2364
	MSE	0.0151	0.0065	0.0008	0.0086	0.015	0.009	0.0047
	SSIM	0.4077	0.5222	0.9147	0.4844	0.385	0.4929	0.5845
Wheel	PSNR	17.1156	20.1539	21.4118	19.2785	17.1331	19.9343	20.1629
	MSE	0.0194	0.0097	0.0072	0.0118	0.0194	0.0102	0.0096
	SSIM	0.5195	0.5838	0.7723	0.5241	0.4916	0.5795	0.5828
Pillars	PSNR	18.496	22.2161	31.9666	21.1297	18.4707	21.9392	25.4875
	MSE	0.0141	0.006	0.0006	0.0077	0.0142	0.0064	0.0028
	SSIM	0.3616	0.4784	0.8793	0.4314	0.3221	0.5019	0.6057
Fish	PSNR	17.6348	21.1703	27.2573	19.6286	17.5731	19.7743	21.056
	MSE	0.0172	0.0076	0.0019	0.0109	0.0175	0.0105	0.0078
	SSIM	0.488	0.5762	0.7998	0.4865	0.4346	0.4919	0.5397
Bird	PSNR	18.269	21.8464	27.9389	20.5116	18.2401	21.5036	22.8991
	MSE	0.0149	0.0065	0.0016	0.0089	0.015	0.0071	0.0051
	SSIM	0.4314	0.5365	0.8606	0.475	0.3955	0.5564	0.5728
Boat	PSNR	18.3267	22.0247	31.4548	20.8323	18.324	21.3002	23.9779
	MSE	0.0147	0.0063	0.0007	0.0083	0.0147	0.0074	0.004
	SSIM	0.3745	0.4871	0.9036	0.4505	0.348	0.5087	0.5755
Cat	PSNR	17.4714	21.1465	31.6374	19.4396	17.4465	19.1847	20.3083
	MSE	0.0179	0.0077	0.0007	0.0114	0.018	0.0121	0.0093
	SSIM	0.3757	0.4799	0.8853	0.4118	0.3405	0.3872	0.4385
Duck	PSNR	17.9393	21.6685	34.2506	20.0632	17.9851	20.3358	22.0137
	MSE	0.0161	0.0068	0.0004	0.0099	0.0159	0.0093	0.0063
	SSIM	0.3067	0.4139	0.9183	0.3793	0.2982	0.4322	0.4731
Street	PSNR	18.3498	22.0584	31.1938	20.8643	18.3268	21.8297	24.4293
	MSE	0.0146	0.0062	0.0008	0.0082	0.0147	0.0066	0.0036
	SSIM	0.3778	0.4961	0.8547	0.4375	0.3338	0.4816	0.5827

Table 5. Results of applying filters on various images in removing speckle noise

Speckle Noise								
Images	**Performance Parameters**	**Noisy Image**	**Gaussian Filter**	**Median Filter**	**Wiener Filter**	**Bilateral Filter**	**Non local Means**	**BM3D**
Barbara	PSNR	19.1493	22.5979	21.9822	23.9693	20.5699	26.3019	25.8915
	MSE	0.0122	0.0055	0.0063	0.004	0.0088	0.0023	0.0026
	SSIM	0.4357	0.5544	0.5047	0.6311	0.5327	0.7289	0.7477
House	PSNR	17.1278	20.8683	21.9189	23.9679	18.3142	25.6088	22.5768
	MSE	0.0194	0.0082	0.0064	0.004	0.0147	0.0027	0.0055
	SSIM	0.2937	0.4048	0.4375	0.5285	0.3384	0.6407	0.4942
Wheel	PSNR	17.1986	19.645	18.7756	21.1361	18.0895	22.6134	21.9818
	MSE	0.0191	0.0109	0.0133	0.0077	0.0155	0.0055	0.0063
	SSIM	0.4233	0.4989	0.4411	0.6011	0.4598	0.7353	0.6458
Pillars	PSNR	20.2093	23.9502	24.9353	25.9524	22.3966	27.5507	28.8621
	MSE	0.0095	0.004	0.0032	0.0025	0.0058	0.0018	0.0013
	SSIM	0.3766	0.5098	0.5279	0.5969	0.4906	0.6465	0.7008
Fish	PSNR	20.0631	23.5925	23.51	24.3512	21.3812	23.4694	24.9712
	MSE	0.0099	0.0044	0.0045	0.0037	0.0073	0.0045	0.0032
	SSIM	0.6331	0.7102	0.6514	0.7077	0.664	0.6546	0.7084
Bird	PSNR	20.4616	23.788	23.8872	24.7758	22.4033	24.5077	25.8392
	MSE	0.009	0.0042	0.0041	0.0033	0.0058	0.0035	0.0026
	SSIM	0.4408	0.5848	0.589	0.7056	0.5819	0.7447	0.7955
Boat	PSNR	17.9287	21.7134	22.8601	24.4504	19.2846	26.9139	24.6002
	MSE	0.0161	0.0067	0.0052	0.0036	0.0118	0.002	0.0035

	SSIM	0.3237	0.4376	0.4712	0.5454	0.391	0.6764	0.5568
Cat	PSNR	22.367	26.0272	26.5843	25.7731	24.2018	23.4893	28.1542
	MSE	0.0058	0.0025	0.0022	0.0026	0.0038	0.0045	0.0015
	SSIM	0.6458	0.7625	0.7466	0.7714	0.7529	0.7097	0.7815
Duck	PSNR	23.1592	26.6561	27.5938	27.5894	26.1339	27.3058	31.0709
	MSE	0.0048	0.0022	0.0017	0.0017	0.0024	0.0019	0.0008
	SSIM	0.4362	0.5963	0.6495	0.7236	0.6586	0.802	0.8726
Street	PSNR	19.7647	23.4619	24.2664	25.0717	21.6794	26.2835	26.8316
	MSE	0.0106	0.0045	0.0037	0.0031	0.0068	0.0024	0.0021
	SSIM	0.373	0.5185	0.5241	0.609	0.495	0.6184	0.6699

5. CONCLUSION

Image denoising is very essential for digital image processing applications. Different type of noises may require different denoising technique. Hence, this paper analyzes the performance of denoising filters for various noise types. Most commonly occurring noise types such as gaussian, poisson, salt & pepper and speckle noises are considered for experiment. Denoising techniques used for comparative analysis are gaussian filter, median filter, wiener filter, bilateral filter, nonlocal means and bm3d. The results obtained by applying these denoising techniques in removing noise with the help of qualitative and quantitative performance metrics. These results play important role in deciding which filter to use for denoising images with different noise types.

6. REFERENCES

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