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Comparative Analysis of Efficient Impulse Noise Removal Techniques applied to Medical Images based on Mathematical Morphology

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Abstract

Analysis of medical images is an important area of interdisciplinary research. Accurate interpretation and understanding of medical images is increasingly demanding for providing accurate diagnosis and detection of diseases. During the image acquisition, imaging devices are frequently subjected to various noise sources. Impulse noise degrades medical image details such as edges, contours and texture. In this paper we present a novel technique for filtering impulse noise on degraded medical images. The proposed filter is based on noise detector and filtering approach. Impulse noise detector using mathematical residues is proposed to identify pixels contaminated by noise, restore them by applying specialized open-close sequence algorithm and recover degraded images by block smart erase method. The proposed method was applied on both simulated and clinical magnetic resonance images with different levels of noise. The results demonstrated the proposed method not only removed salt and pepper noise but also effectively preserved the image details till noise level of 90%. Compared with several existing noise filtering models, the novel filter has demonstrated to be effective for noise removal, image detail preservation and clinical practice. Findings suggest that by using denoising algorithms, a potential reduction of 90% in noise is possible with no loss of image quality.

Keywords: Denoising, medical imaging, impulse noise, signal to noise ratio.

Introduction

Medical imaging is a popular technique to view the internal organs without incursion of human body. Various effective algorithms are formulated to solve the medical imaging problems. Noise can occur in MR images during two phases, acquisition and transmission[1]. During the acquisition phase, noise can occur in an image due to two reasons. The image acquisition devices are susceptible to thermal noise and statistical randomness in emission of photons. The physiological interference inability of a patient to remain static. The noise in the images is inevitable, and hence, removing the noise is mandatory for improving the quality of the images for accurate diagnosis by doctors[1,2]. Impulse noise is prevalent in medical images due to quick image record and image transmission and occurs in the signal channels of medical imaging equipment[3]. Two techniques are available to reduce such noise. Get a second image which increases acquisition time, cost of the medical equipment and investigation. Apply some image processing technique to reduce noise in an acquired image lowering acquisition time, the computational load and cost of the machine[3,4].

A typical form of impulse noise in medical image is salt and pepper noise which represents itself as randomly occurring white (salt) and black (pepper) pixels. Here, pixels are randomly corrupted by two fixed extreme values, 0 and 255 (for gray level image), generated with the same probability. When the noise density is P, the noise density of both salt (P1) and pepper (P2) is P/2. Here, we only focus on removing the fixed impulse noise occurring in medical images[3,4]. To preserve the integrity of edge and detail information associated with the medical image, the impulse noise needs to be removed. Non-linear techniques provide better results than linear methods[5-9]. These nonlinear techniques are capable of preserving the medical image detail till noise level of 30%. In this paper, we propose a novel filter to restore medical images that are corrupted by 10%–90% of impulse noise.

Material and Methods

Materials: The proposed approach was evaluated with images acquired using Spin Echo Sequences with long repetition time (TR) and short echo time (TE) by Philips and Siemens scanners. The detailed information of the imaging scanners is as follows:

Philips 1.5T scanner: T2 weighted axial MR brain image of tumor pathology. With acquisition parameters are TR=5 sec, TE=105msec, slice thickness=5.0mm, Resolution of 560x560, field of view size =958x958.

Philips 3.0Tscanner: PD (proton density) weighted sequence of MR knee image with ligament, with the acquisition parameters are TR=4.6sec, TE=30ms, slice thickness=2.5mm, resolution of 672x672.

Philips 1.5T scanner: Acquisition parameters are TE=105ms,TR=5.1sec, slice thickness=1.0mm, resolution of 12x512, with acquisition parameters are TE=105ms,TR=5.1sec, slice thickness=1.0mm, resolution of 512x512.

Siemens CT VAO COAD Scanner: Acquisition parameters are, Slice thickness=3mm, exposure time=1msec, x-ray tube urrent=100mA. Resolution of 512x512 with acquisition parameters are, Slice thickness=3mm, exposure time=1msec, x-ray tube current=100mA. Resolution of 512x512.

Method: A noise removal filter is proposed to be developed is improved method based on morphological filter to restore the original image from its degraded and noisy one[10]. The method is divided in two main steps. The first one is a preliminary identification of corrupted pixels in an effort to avoid the processing of pixels which are not corrupted by impulse noise. In the second one the filtering method is applied only to those pixels are identified as noise in the first step. The proposed block diagram is as shown in figure-1.

Morphological Residue Detector (MRD): The morphological operators are used to detect noisy pixels in the residue detector. Since the open removes salt noise and close removes pepper noise, through the operators the salt and pepper pixels noises can be notably determined[11-13]. In general, these transformations find structures which have been removed by the opening and closing filters and the residual between the original image and the filtered image increases notably the contrast of the erased regions. So, the open-close transformations are defined in equation 1-2.

$$D_0(i,j) = f - f \circ b \quad (1)$$

$$D_c(i,j) = f \bullet b - f \quad (2)$$

The noise pixels are detected by comparing above two images with a threshold T are defined in equation-3.

$$r(i,j) = \begin{cases} 1, & D_0(i,j) \geq T \text{ and } D_c(i,j) = 0 \\ -1, & D_0(i,j) = 0 \text{ and } D_c(i,j) \geq T \\ 0, & \text{otherwise.} \end{cases} \quad (3)$$

If r(i,j) is 1, then $D_0(i,j)$ is considered as salt noise or if r(i,j) is-1, as pepper noise. When one of these two types of noisy pixels is detected, the corresponding generalized open-close sequence algorithm is applied. If r(i,j) is 0, the pixel is considered as noiseless and put forward without change.

Open-Close Sequence Algorithm (OCS): Two filters using open close sequences are applied to the corrupted pixels. The first one, which is called open-close filter (OCF) is defined in equation-4.

$$OCF(f) = (f \circ b_1) \bullet b_2 \quad (4)$$

Where: b_1 and b_2 are two Structuring elements are introduced to remove salt noise pixels. Here the size of b1 is small enough to preserve the details of the image. And the size of b2 is larger than that of b1 to remove pepper noise pixels which is not removed by opening filter. The close-open sequence filter is defined in equation-5.

$$COF(f) = (f \bullet b_1) \circ b_2 \quad (5)$$

Analogous to the previous filter this filter is normally removes the pepper noise pixels. However, the noise whose size is larger than that of structuring element b1 will not be removed and they are propagated in the image. Which leads to the generation of some undesired white (or black) blocks in the image. To avoid this effect, block smart erase algorithm is introduced. It is based on the median of the surrounding pixels. The details of the proposed BSE is as follows.

Block Smart Erase Algorithm: The existence of undesired white and black blocks that will degrade the quality of image, black smart erase algorithm is proposed to remove such effects is concept based on median effect replaces by its surrounding pixels. The details of the proposed algorithm is as shown below.

Proposed algorithm implementation: Propose an NXN size of matrix is fixed at the center to test the pixel (recommended value of N should be 5, 7 or 9) a large value of N should be suggested.

If If $A(i, j) \in \{0, 255\}$ we have an absolute extreme value is tested, follow the step 3 in the below. Otherwise the pixel is remains unaltered.

If the value of the pixel is 0 or 255(salt or pepper noise), its values is replaced by the median value of their surrounding pixels.

Algorithm step is repeated for the next size of window.

Results and Discussion

Performance comparison: Performance of the proposed novel filter is evaluated and compared with the standard filters for filtering medical images degraded by impulse noise. Medical images such as brain, knee and sinusitis images acquired from MRI and CT modality and it is corrupted with low, medium and high impulse noise, their dynamic ranges is [0,255] where 0 represents the salt noise and 255 represents pepper noise with equal probability. In the experiments, the noise levels varied from 10% to 90% will be tested. We have not increased the percentage of impulse noise for above 90%, because the methods remove effectively the noise but the edges are not preserved, except the Standard filters (MDF, CWM, SMF) which performs badly in both aspects[5-9].

To compare the performance parameter of our filtering algorithm versus other methods, its results are shown through PSNR(DB),from 10% to 90% of impulse noise are shown in table-1 and figure-2 for the MR modality of brain image of tumor pathology corrupted 50% of impulse noise. From this the performance of the proposed filter is better than the other standard filters when the noise ratio is higher than 30%,and represents poor performance at the beginning of the range(≤30%) and performance well when the noise ratio is high (≥30%).In the case of above 90% all filters have a behavior which a detail-preserving regularization is not obtained and the edges are not preserved. These conclusions can be extended to the other images since similar curves were obtained with these other ones. Also, in figure-6 the plots of PSNR curves versus noise level for the "MR knee" image can be observed. Therefore, the odd behavior of the OCS algorithm can be observed. Note that it obtains a worse result for the image corrupted with 10% of noise than for the one corrupted with 20%. On the other hand, the OCS is more robust in this sense since the curve is strictly decreasing as well as the rest of the algorithms. From figure-2 to figure-13 we present restoration results for several different noise levels and images. As we can see from Figures 3, 9 and 12, the OCS algorithm gives the best performance in terms of noise suppression and edge preservation. If noise level exceeds 90%, our OCS filter remove the noise effectively but sharpness along the edges and the pathology structure is extensively blurred. So, the proposed novel filter can remove most of the noise effectively while well preserving the edge details of the image is required for the clinical practice.

Validation on real clinical MR and CT data: The restoration results obtained for the T2 axial MR brain image of tumor pathology, PD (proton density) weighted sequence of MR knee image with ligament, T2 axial CT head corrupted 50% of Impulse noise, CT sinus head sequence with infected mucous images are corrupted by 10-90% of impulse noise respectively shown in figsures-2 to 13 and table1-8. From these results the proposed filter remove noise at higher levels applied to four data types producing more detailed information of the medical image in which all the distinct features are well preserved and it is important for clinical practice. The performance parameters (PSNR and IQI values) obtained for the T2 axial MR brain image of tumor pathology having different noise levels from 10-90% using efficient denoising techniques are given in figure 3 and figure 4 (PSNR and IQI graph). Table-1 and table-2 shows the experimental results (PSNR and IQI values) obtained for the T2 axial brain image corrupted by 10-90% of impulse noise respectively. Similarly the results obtained for the MR sinusitis, MR knee and CT sinusitis corrupted by impulse noise are shown in table 3-8.From these results, we observe that higher the value of PSNR and IQI shows that the proposed filter perform superior than the other denoising methods

Image quality evaluation metrics: The PSNR is most widely used image quality metrics evaluated in decibels (DB) and is inversely proportional to mean squared error (MSE) after denoising. The peak signal to noise ratio in decibel (dB) is measured using the following formula[14].

$$PSNR = 10\log\frac{255^2}{MSE} \quad (6)$$

$$MSE = \frac{1}{MN}\sum_{x=1}^{M}\sum_{y=0}^{N}[u(x,y) - v(x,y)]^2 \quad (7)$$

The PSNR does not account for the similarity between image structures, only for the similarity between gray levels. Hence we need to define another quality metrics called image quality index(IQI) which takes in to account of the similarity between the edges(high frequency information) between the restored image and the original image are defined in the following equation-8.

$$IQI = \frac{\sigma_{fg}}{\sigma_f\sigma_g}\frac{2\,\bar{f}\,\bar{g}}{(\bar{f})^2+(\bar{g})^2}\frac{2\,\sigma_f\sigma_g}{\sigma_f^2+\sigma_g^2} \quad (8)$$

All experiments were performed using MATLAB 2010a (The Math Works, Inc., Natick, MA). Median filtering was computed using the MATLAB Image Processing Toolbox (function Median) and the noise variance from 10-90% were added to the image using MATLAB function (Imnoise) and the performance of the standard filters were compared with the proposed filter[15].

Table-1
Image quality evaluation Parameters of MRI Brain Image (560x560) corrupted by Impulse noise

Noise Variance	PSNR ratio in dB					
	MDF	**AMF**	**CWM**	**DBA**	**SMF**	**OCS**
10	18.01	20.51	21.22	22.11	23.01	31.22
20	17.65	19.66	20.33	21.42	22.36	29.23
30	15.22	16.11	18.25	19.16	21.01	27.41
40	14.16	15.16	17.53	18.44	20.71	26.08
50	13.22	14.11	16.16	17.22	20.12	24.77
60	12.01	13.05	13.14	14.34	17.88	23.34
70	10.22	10.25	12.13	13.13	18.13	22.16
80	9.53	10.11	11.55	12.17	18.11	21.22

90	8.16	10.04	11.01	12.03	16.78	17.22

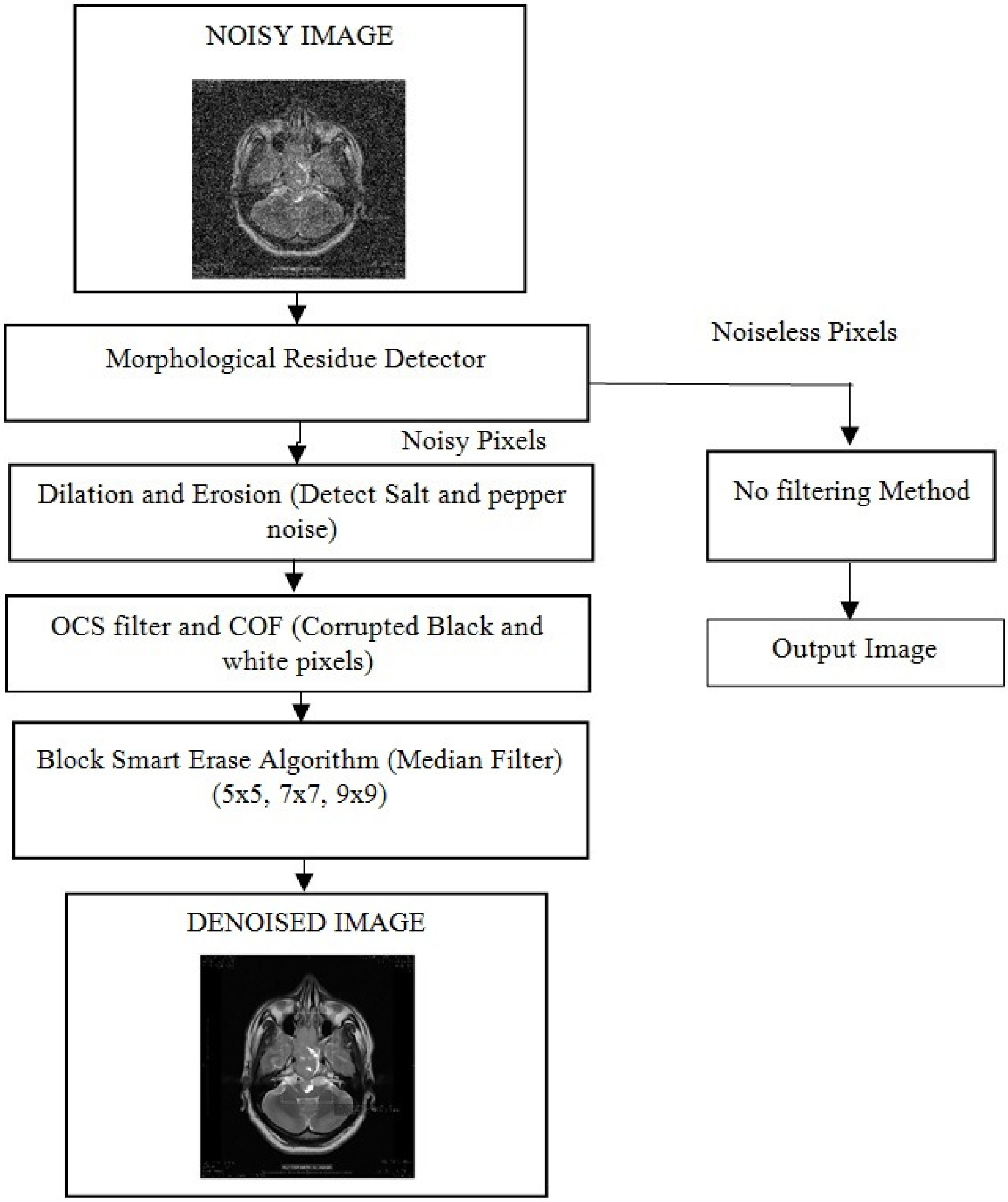

Figure-1
Proposed block diagram

Conclusion

Medical imaging is a powerful diagnostic technique in the clinical application. However, the incorporated noise during image acquisition degrades its ability for the human interpretation or computer-aided analysis. Time averaging of image sequences aimed at improving the SNR would result in additional acquisition time and reduce temporal resolution. Therefore, denoising should be performed to improve the image quality for more accurate diagnosis. In this paper we have presented a novel filter by integrating noise detector with OCS filter for effective noise removal in medical images degraded by impulse noise. The drawback of proposed filter is, if the noise level increases beyond 90% it removes the noise but does not preserve the edges well. The performance can be increased by proper selection of threshold value and size of structuring element.

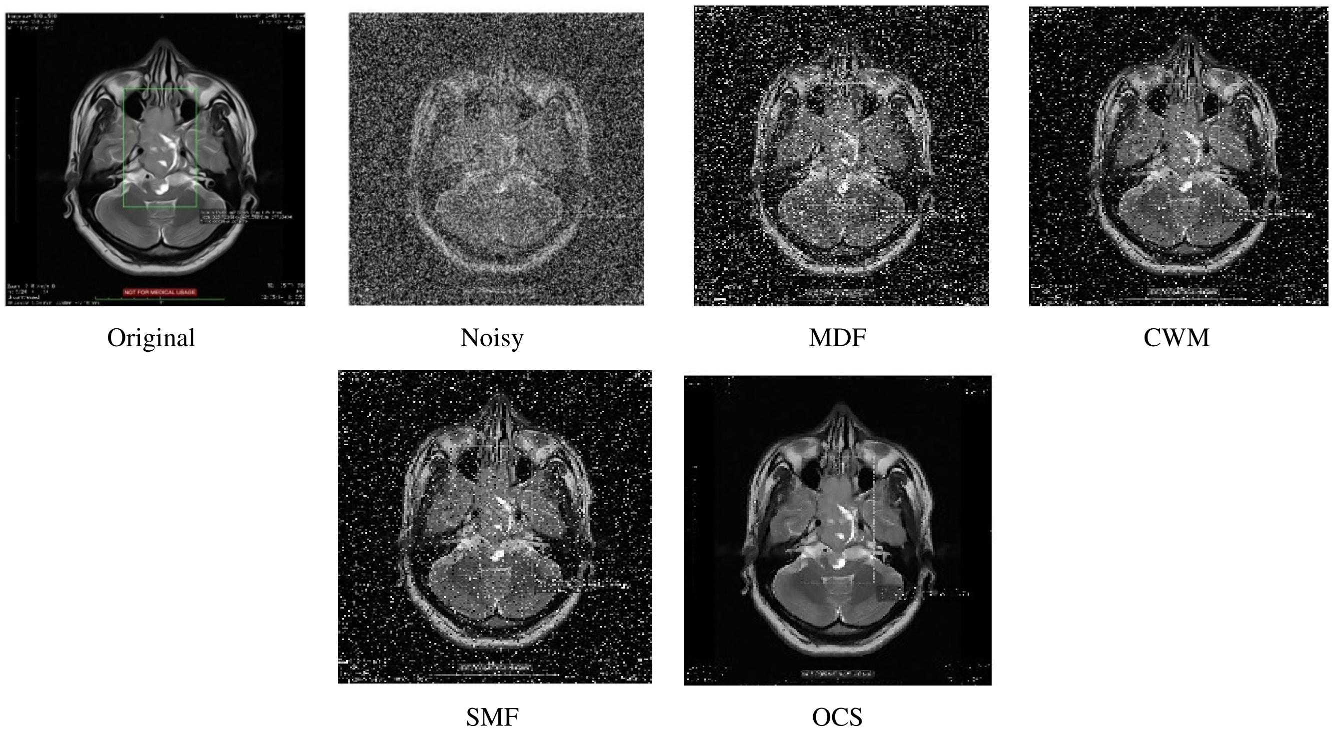

Figure-2
Restoration Results of T2 weighted axial MR brain image of tumor pathology corrupted 50% of Impulse noise

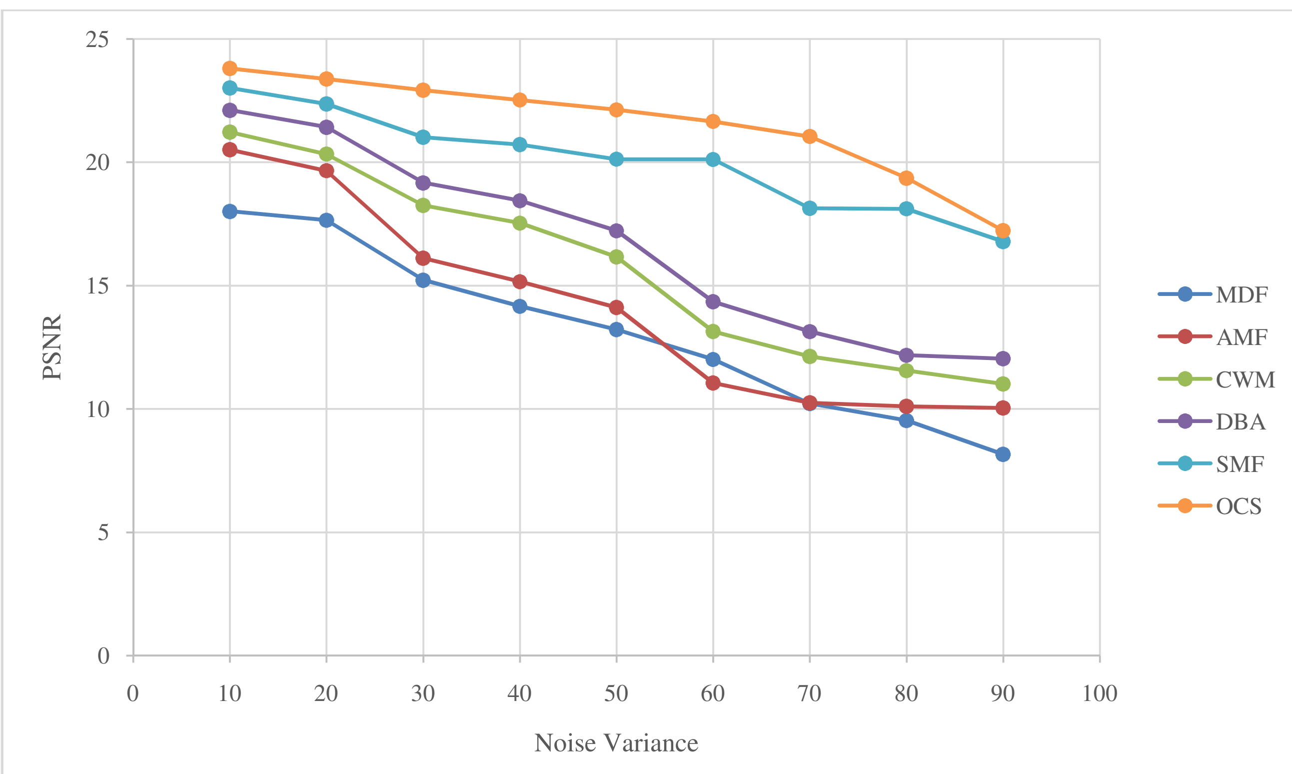

Figure-3
Qualitative performance metrics

Table-2
IQI samples obtained for MRI Brain Image (560x560)

Noise Variance	IQI					
	MDF	**AMF**	**CWM**	**DBA**	**SMF**	**OCS**
10	0.39	0.42	0.59	0.69	0.79	0.974
20	0.35	0.41	0.49	0.59	0.66	0.963
30	0.25	0.36	0.39	0.46	0.59	0.952
40	0.15	0.19	0.29	0.35	0.58	0.943
50	0.14	0.16	0.28	0.33	0.56	0.932
60	0.13	0.14	0.16	0.22	0.55	0.925
70	0.05	0.13	0.18	0.19	0.48	0.914
80	0.025	0.03	0.04	0.16	0.39	0.890
90	0.012	0.013	0.015	0.09	0.36	0.873

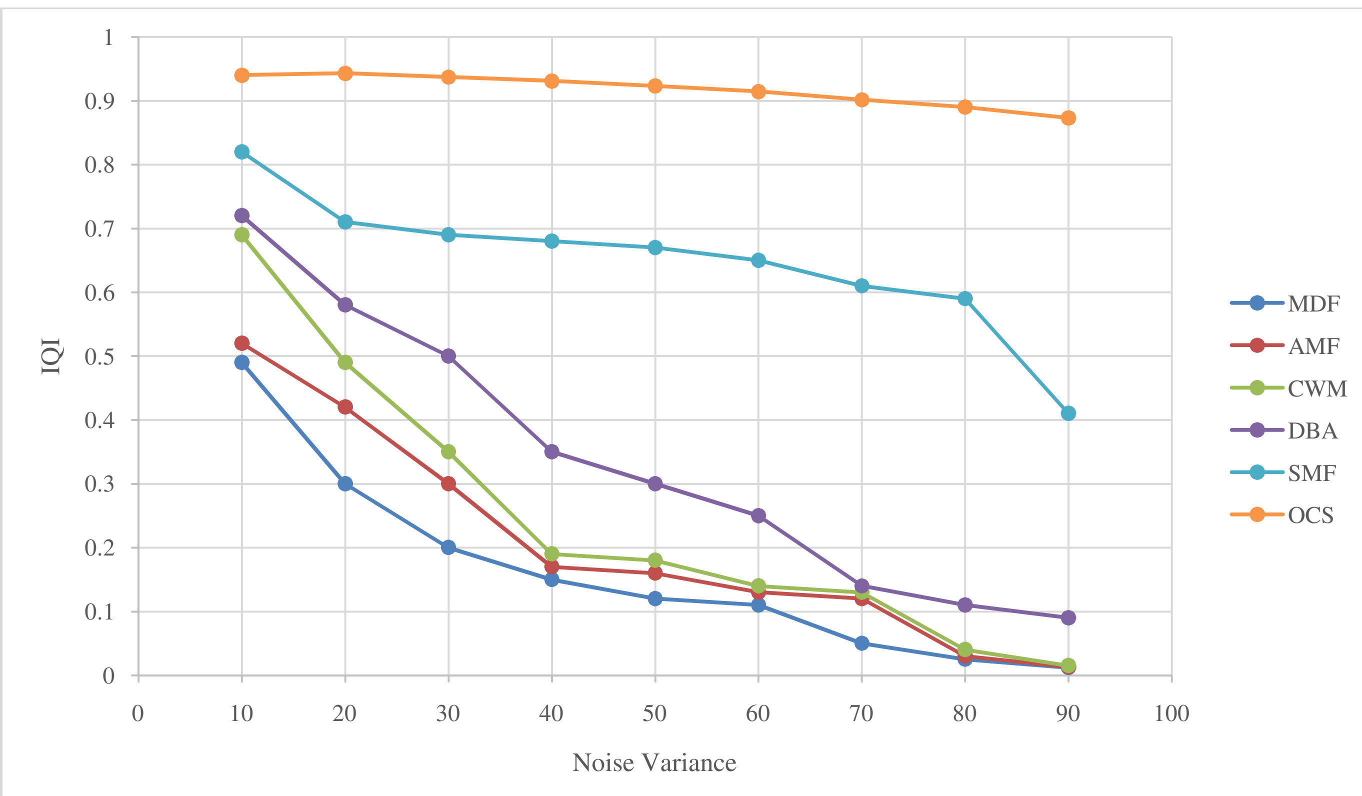

Figure-4
Graphical Representation of IQI

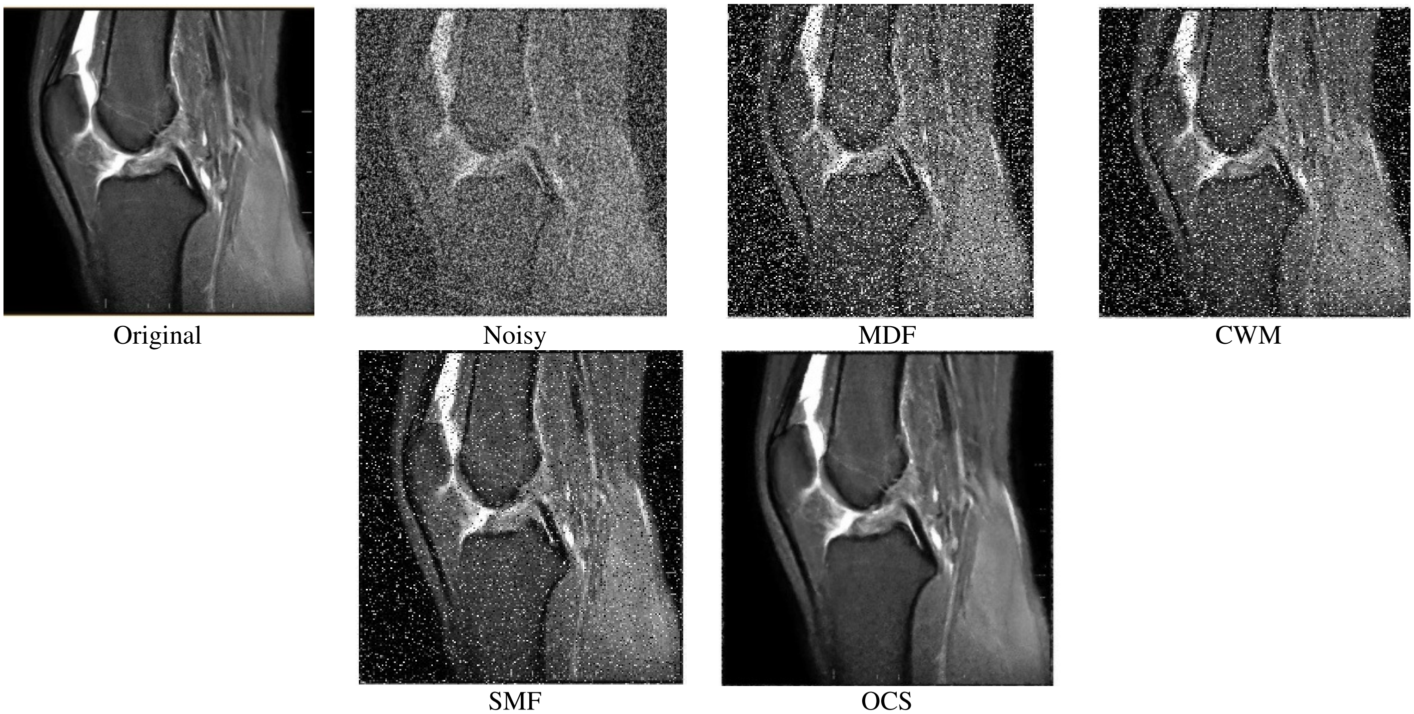

Figure-5
Denoising Results forPD (proton density) weighted sequence of MR knee image with ligament corrupted 50% of Impulse noise

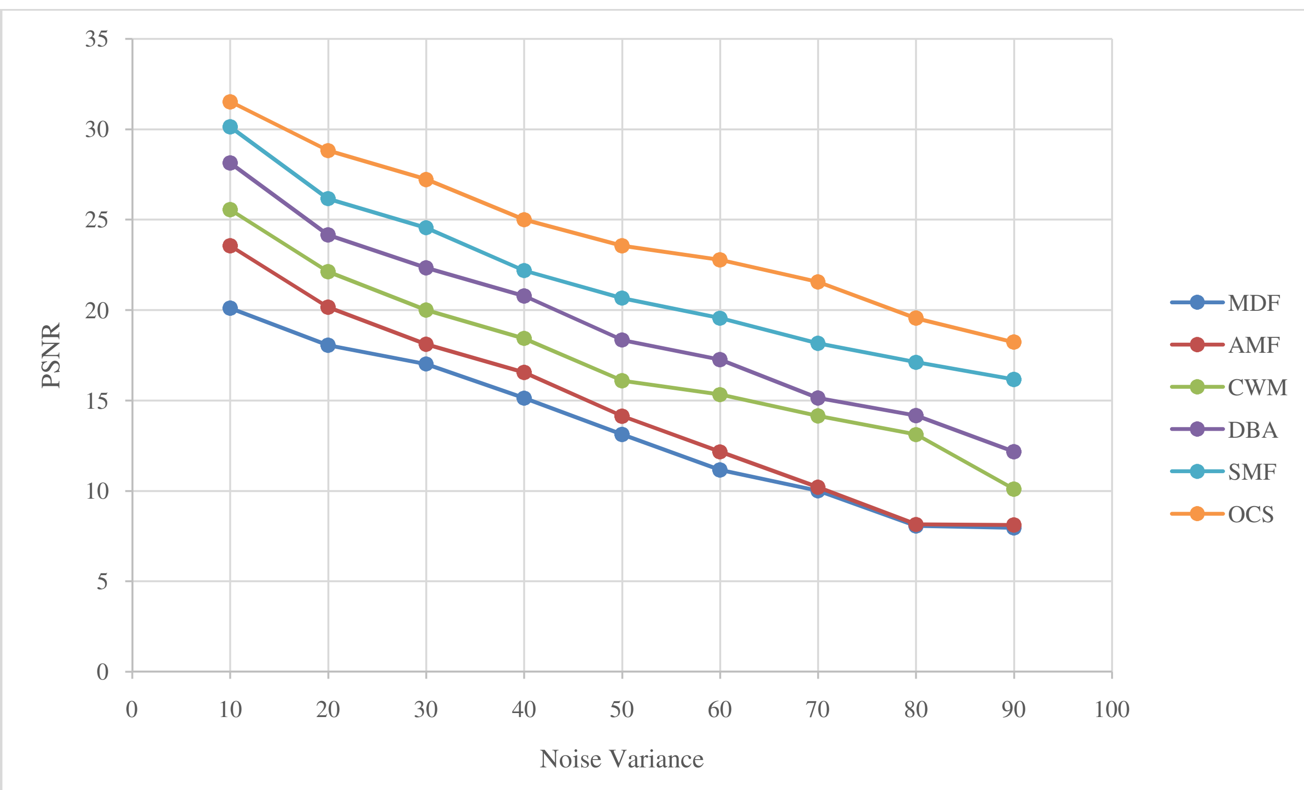

Figure-6
Qualitative performance metrics

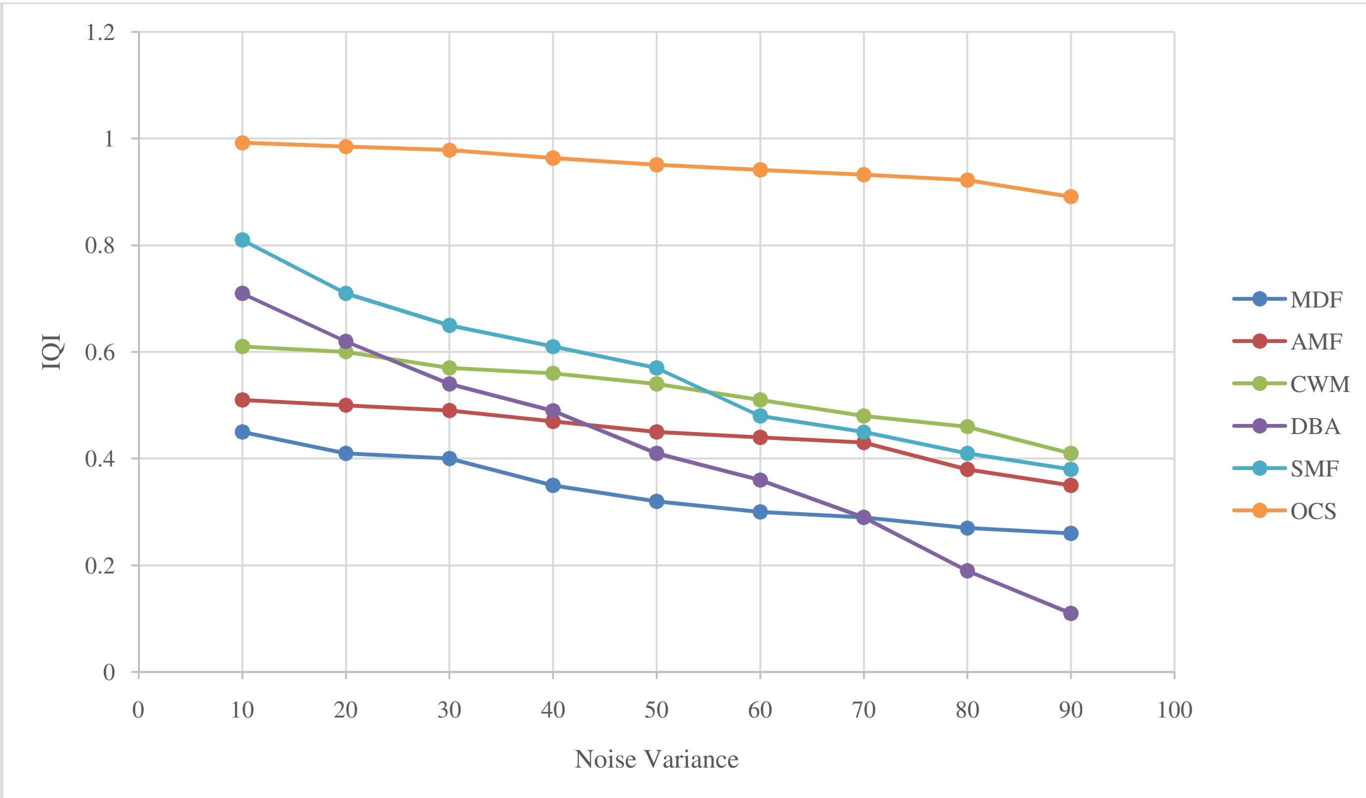

Figure-7
Graphical Representation of IQI

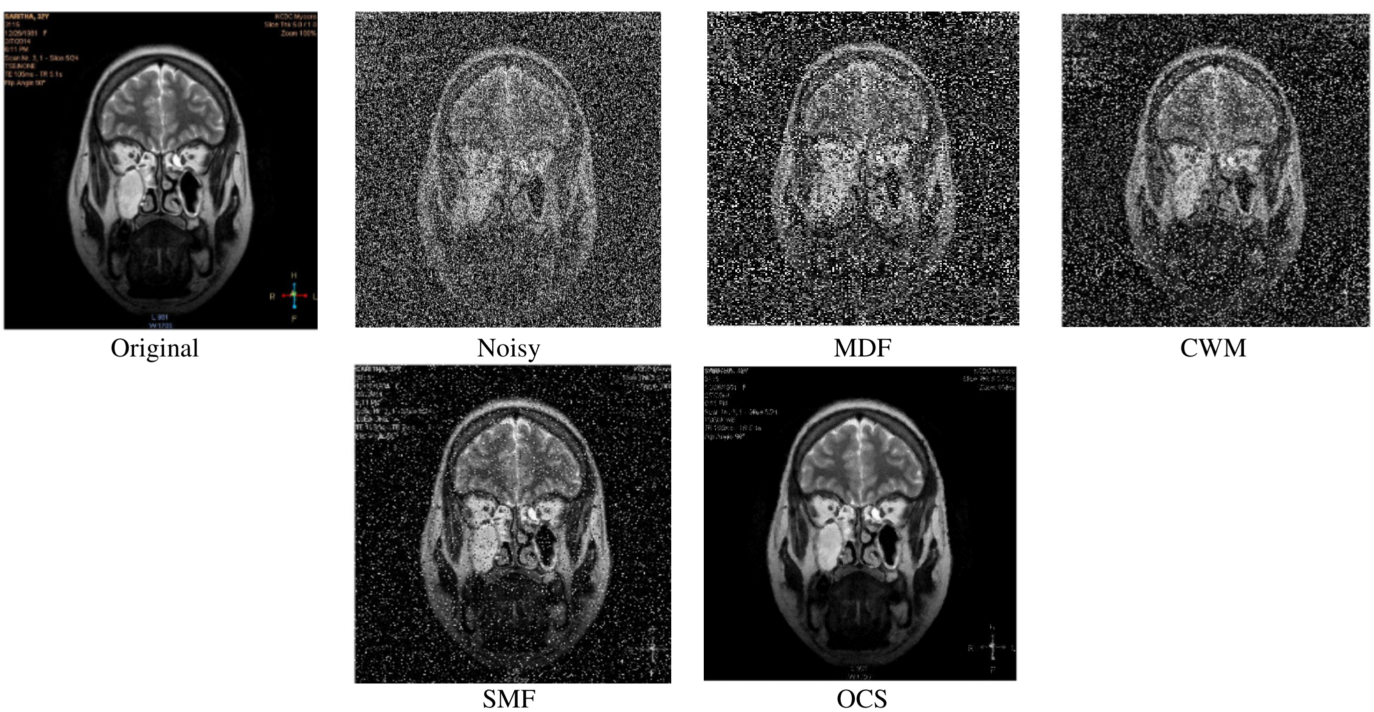

Figure-8
Denoising Results for T2 weighted axial MRI head with infected sinusitis image at the left sidecorrupted 50% of Impulse noise

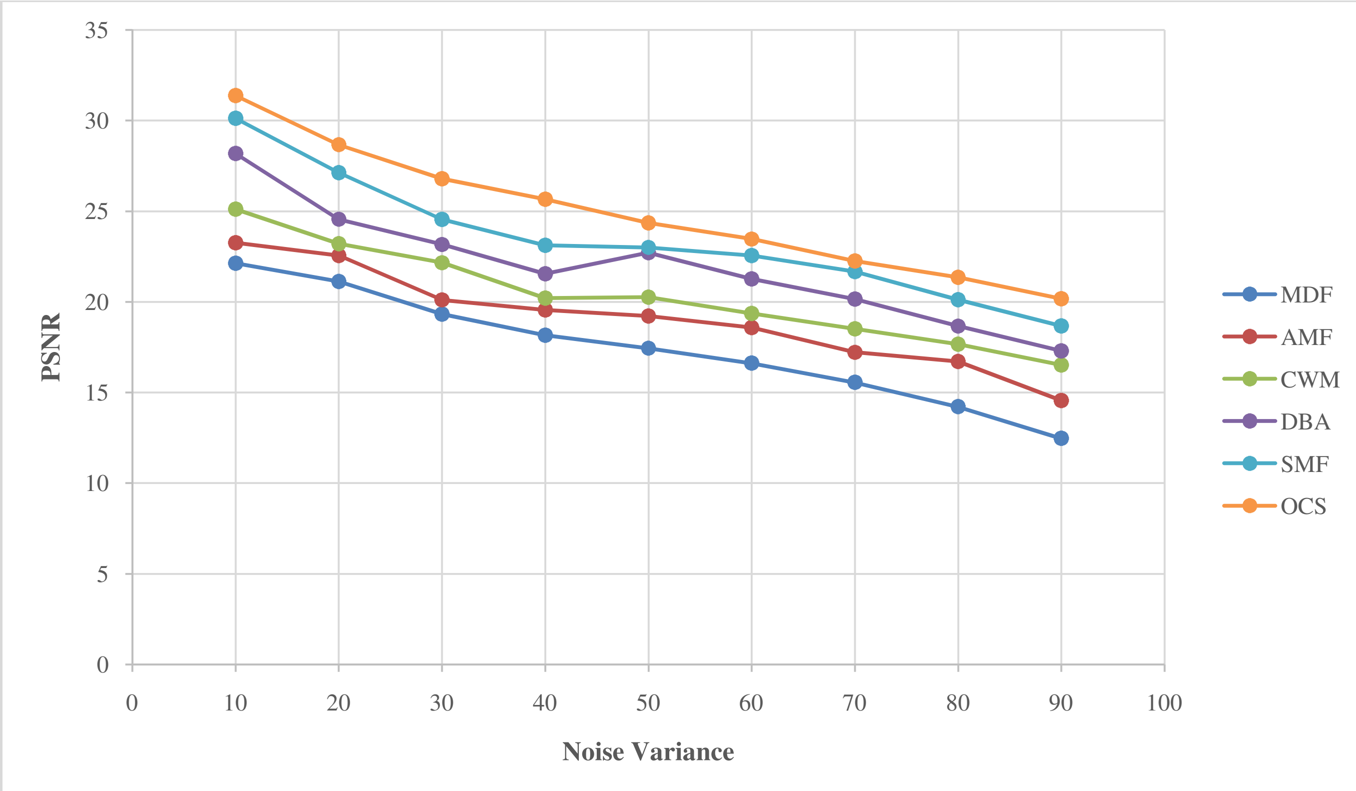

Figure-9
Qualitative performance metrics

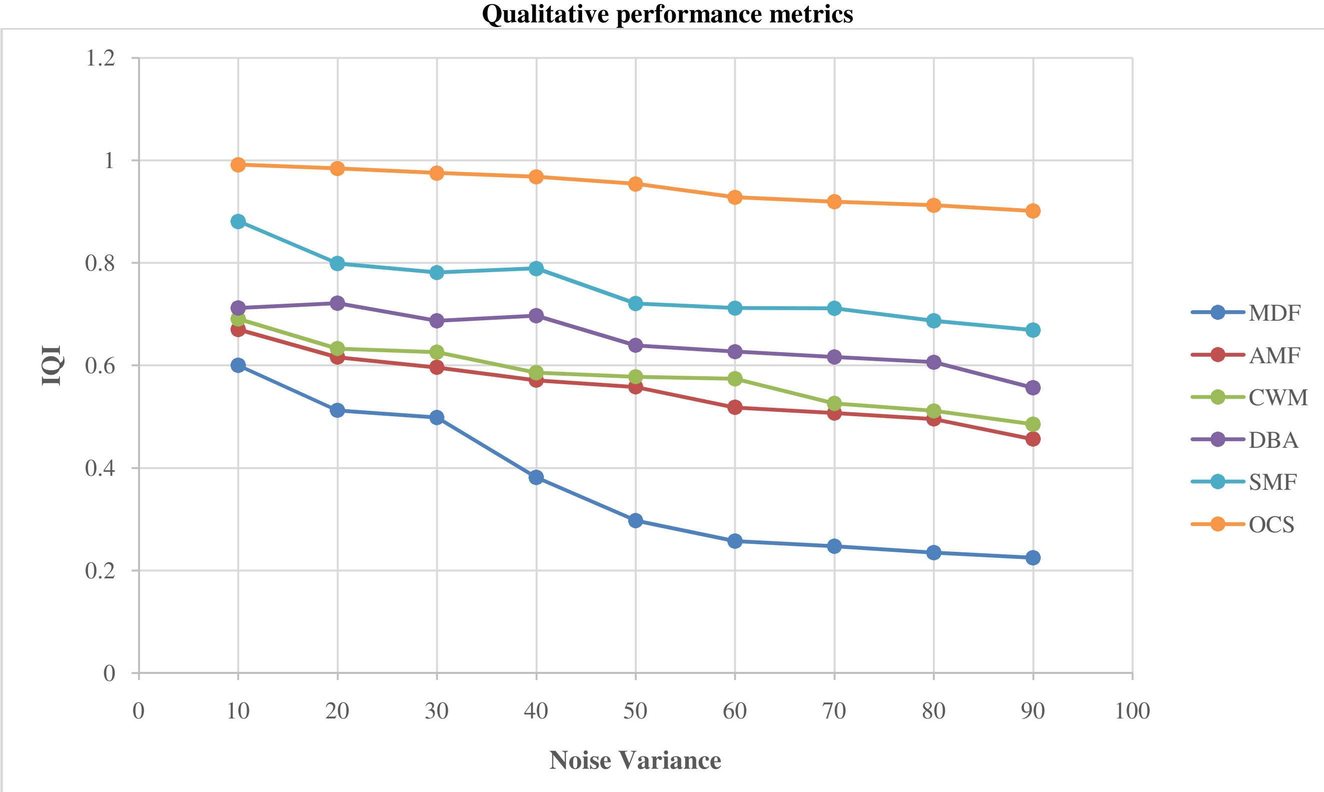

Figure-10
Graphical Representation of IQI

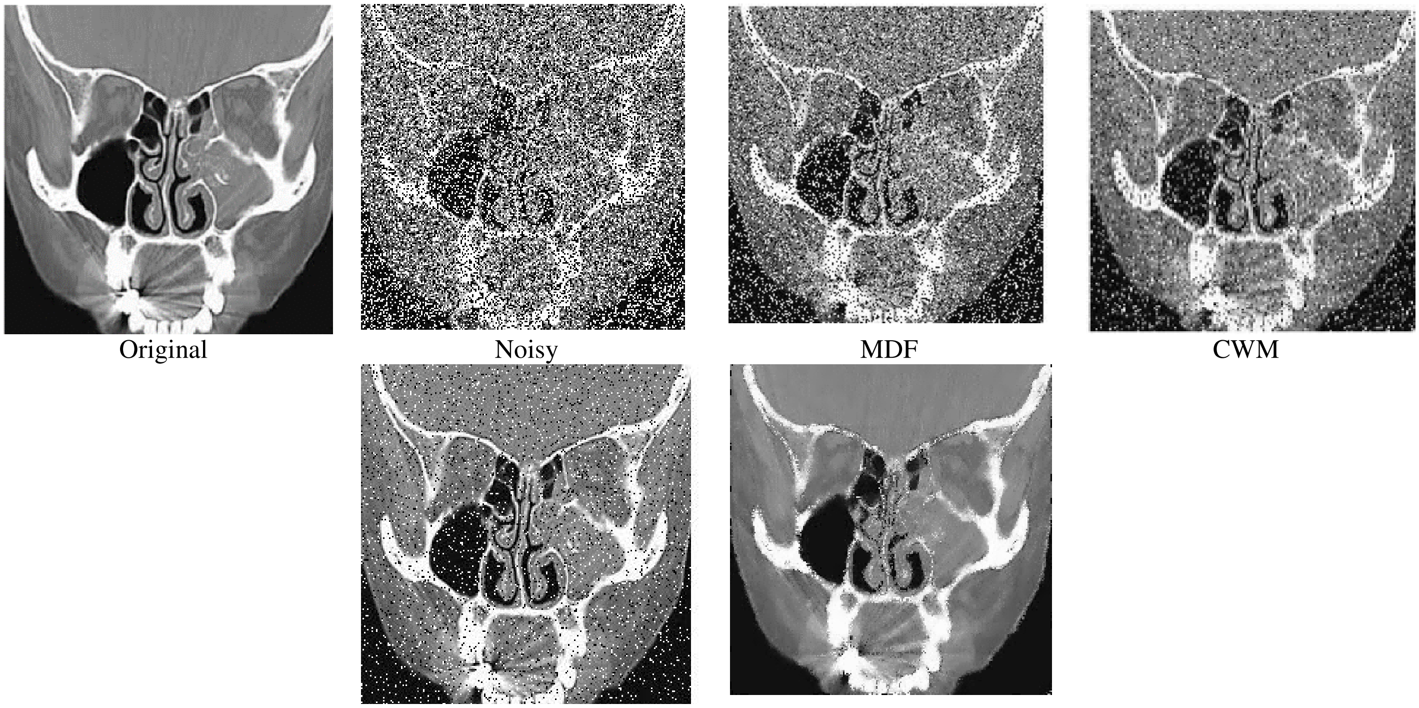

Figure-11
Restoration Results of T2 weighted sequence of MR head with infected sinusitis image at the left sidecorrupted 50% of Impulse noise

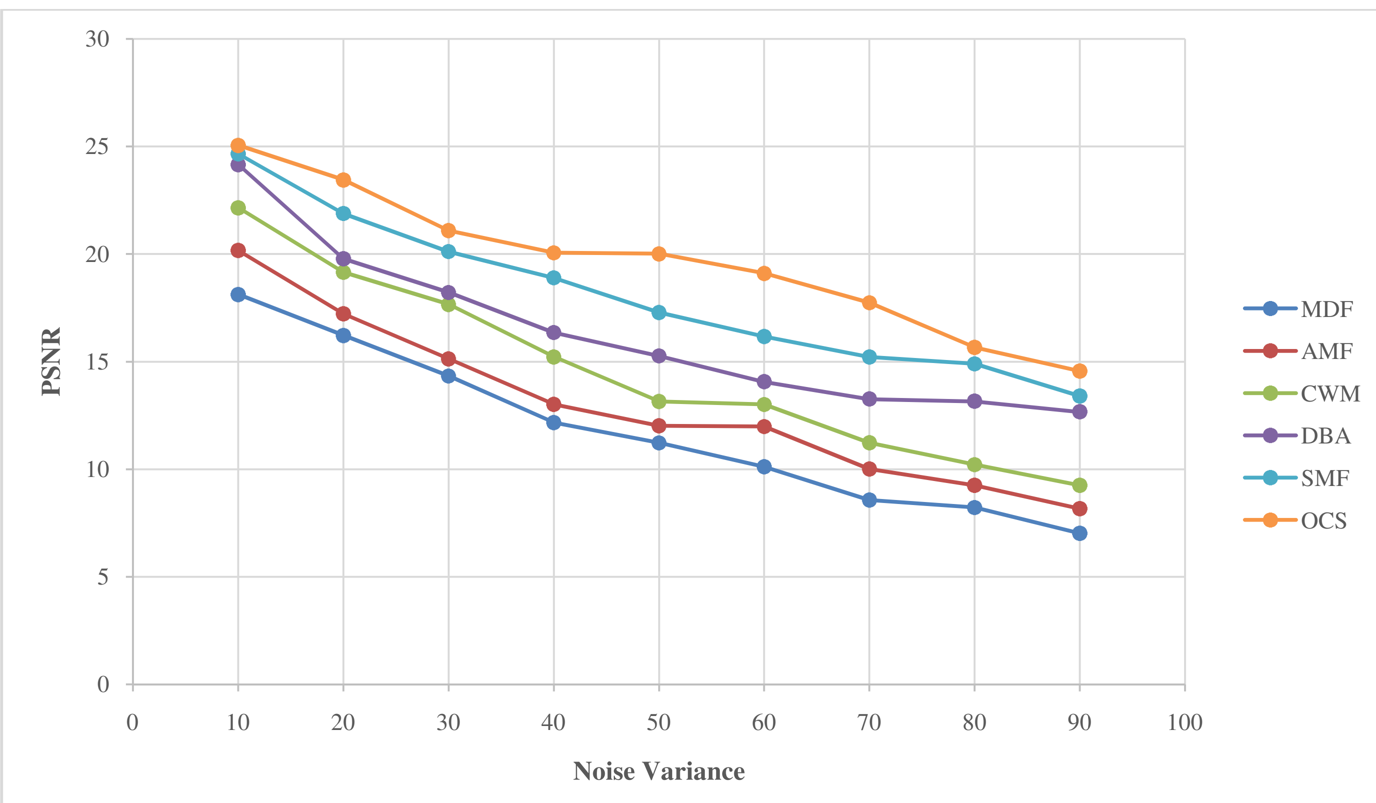

Figure-12
Qualitative performance metrics

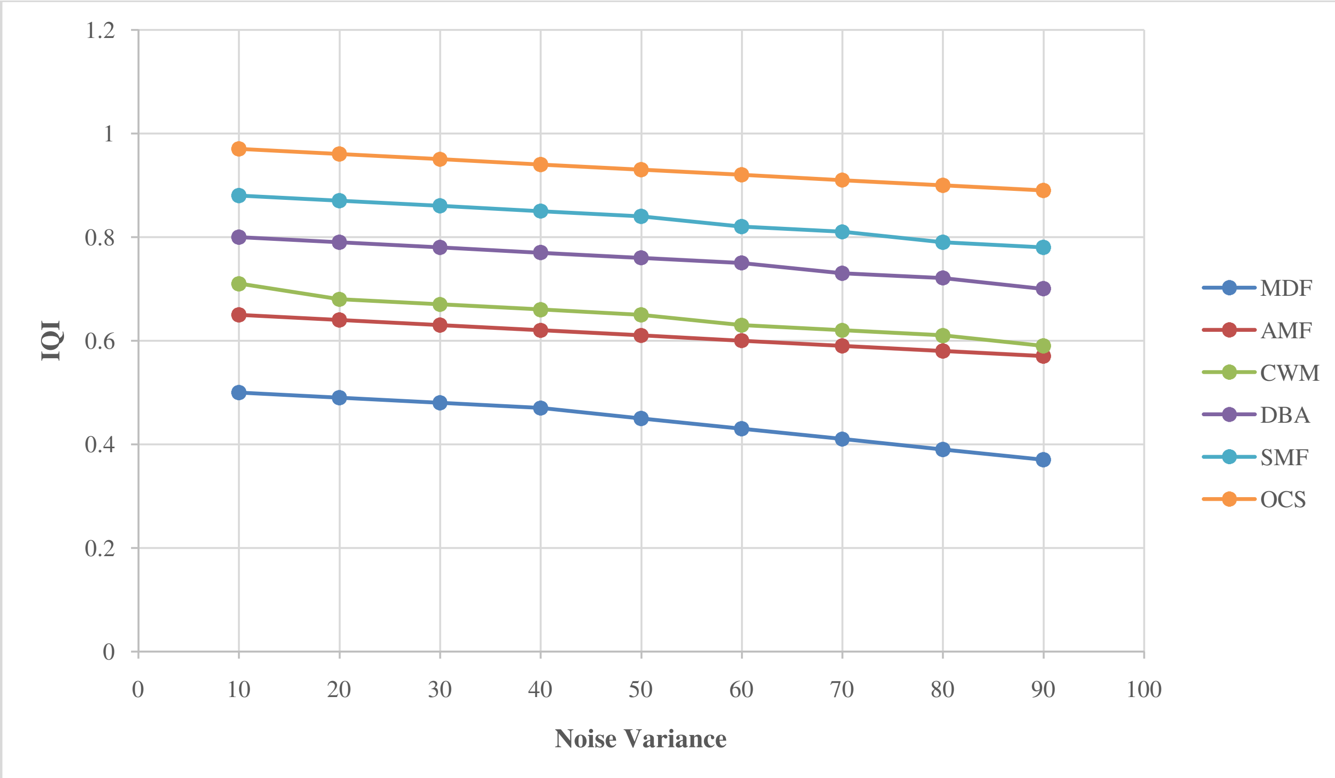

Figure-13
Graphical Representation of IQI

Abbreviation: MDF; Median filter, AMF; Adaptive Median filter, CWM; Center weighted Median filter, SMF; Switching Median filter, DBA; Decision Based algorithm, OCS; Open Close Sequence Algorithm, IQI; Image Quality Index, PSNR; Peak Signal to Noise Ratio, MRI; Magnetic Resonance Imaging, CT; Computed Tomography

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