Development of mathematical morphology filter for medical image impulse noise removal

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Abstract- Post-acquisition denoising of medical images is of importance for clinical diagnosis and computerized analysis, such as tissue classification and segmentation. During the image generation, imaging devices are quite often interfered by various noise sources. Impulse noise which causes the medical images to remove important image details such as edges, contours and texture. In this paper, a new filtering method is proposed to remove impulse noise on degraded medical images. The proposed filter is integrated with noise detector and filtering approach. An impulse noise detector using mathematical residues is proposed to identify pixels that are corrupted by impulse noise, and the image is recovered using specialized open-close algorithm that is only applied to the noisy pixels. Black and white blocks that degrade the quality of the image will be recovered by a block smart erase method. The proposed method was tested on simulated medical images from a brain web database and clinical medical images with different levels of noise. The results show that the morphology filter produces better denoising results in terms of qualitative and quantitative measures compared with other denoising methods, compared with several existing noise filtering models demonstrated that not only the proposed filter is effective for noise removal but also for image detail preservation and clinical practice.

Keywords: Medical images, Impulse noise, Signal to noise ratio.

1. INTRODUCTION

Noise occurs [1] in Medical images due to patient movement and acquisition device. As the noise in the images is inevitable, removing the noise is necessary for improving the quality of the images for accurate diagnosis by doctors. Impulse noise [2] is prevalent in medical images due to quick image record and transmission and occurs in the signal channels of medical imaging equipment. The typical form of impulse noise in medical image is salt and pepper noise [3, 4] which represent 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. That is, when the noise density is P, the noise density of salt (P1) and pepper (P2) is P/2. In this paper we only focus on removing the fixed impulse noise occurring in medical images. In case of diffusion weighted MRI imaging [5] sequence, like neuro imaging, sinusitis imaging, images in regions with low signal levels causes high noise. To reduce the SNR, several repeated acquisitions are averaged to reduce noise variance. This approach requires long acquisition time and is not acceptable for clinical applications where patient cannot remain still for extended periods of time. Denoising techniques can be applied to improve the image quality as a post processing step, thereby not increasing the scan time of the machine.

In the current models of the MRI machines, the Signal to noise Ratio (SNR) depends mainly on the strength of magnetic fields of the system. Increasing the strength of the magnetic field, improves the SNR but introduces artifacts, and requires high power supply devices leading to high costs [6]. Potential exists for practical application of the denoising method to boost SNR and hence reduce scan time in low magnetic field scanners.

To preserve the edge details of the image and detail information associated with the medical image, the impulse noise needs to be removed. Non-linear techniques provide better results than linear methods. These nonlinear techniques [7, 8, 9] 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 30%–80% of impulse noise.

978-1-4673-9563-2/15/$31.00 ©2015 IEEE

2. Materials and Methods

2.1. Materials

The experiments were conducted on two MRI datasets. The first dataset consists of simulated MRI obtained from the Brain web database [10]. The second dataset consists of clinical MRI collected from Karnataka Diagnostics Laboratory (KDL), Mysore, Karnataka, India.

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.

2.2. 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. (1).

$$PSNR = 10 * \log \frac{255^2}{MSE} \qquad (1)$$

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.(2).

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

A noise removal filter is proposed to be developed based on morphological filter to restore the original image from its degraded and noisy one. The proposed method is divided into three modules: Morphological Residue Detector (MRD), Open Close Sequence (OCS) module and Block Smart Erase (BSE) module. The block diagram of the proposed filter is as shown in Fig.(1).

2.3. Morphological Residue Detector

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. 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. (3)-(4).

$$D_0 = f - f \circ b \qquad (3)$$

$$D_c = f \bullet b - f \qquad (4)$$

The noise pixels are detected by comparing above two images with a threshold T are defined in equation.5.

$$r(i,j) = \begin{cases} 1, & D_0(i,j) \geq T \text{ and } D_c(i,j) = 0 \\ -1, & D_0(i,j) = 0 \text{ and } D_c(i,j) \geq T \\ 0, & otherwise. \end{cases} \qquad (5)$$

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.

2.3.1. Open-close sequence algorithm

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.(6).

$$OCF(f) = (f \circ b_1) \bullet b_2 \qquad (6)$$

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.(7).

$$COF(f) = (f \bullet b_1) \circ b_2 \qquad (7)$$

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.

2.3.2. Block Smart Erase (BSE) 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.For an NXN window centered at the test pixel, where N would normally be 5, 7, 9, larger value is suggested.

1. 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.

2. If If A(i, j) ∈ {0, 255} we have an absolute extreme value is tested, follow the step 3 in the below. Otherwise the pixel is remains unaltered.
3. 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.
4. Algorithm step is repeated for the next size of window.

Proposed MRI denoising method based on morphological OCS filter is proposed and summarized as below (also see Fig.1.):

Step1: Corrupted MRI Image is applied to the Residue Detector which predominantly identifies corrupted pixels.

Step2: Dilation and Erosion output the maximum and minimum values in the structuring element domain, determined by the salt and pepper noise (Impulse noise).

Step3: This corrupted impulse noise is removed by opening and closing filter.

Step4: A simple and efficient BSE algorithm is proposed to eliminate undesirable effects of extreme pixels by replacing their values by the median value of the surrounding pixels.

Step5: Finally the medical image corrupted by impulse noise is reconstructed and restored.

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 [13].

3. Experiments and Results

3.1. Performance comparison

The filtering performance of the proposed method applied to noisy images corrupted by impulse noise is evaluated and compared with other well-known methods [14]. The performance of the algorithm is tested with different medical images (MRI and CT) of brain, knee, and sinusitis with low, medium and high corrupted impulse noise. A wide range of noise levels from 30% to 80% with increments of 10% are tested. If noise level exceeds 80%, our proposed filter removes the noise effectively but sharpness along the edges and the pathology of the structure is extensively blurred. The proposed filter can remove most of the noise effectively while preserving the edge details of the image required for clinical practice.

3.2. Validation on real clinical MR and CT data

The denoising results of the MRI brain image corrupted by 30% of impulse noise are shown in Fig.2. Similarly this can be extended to 80% and the results for this as well as clinical dataset images of different types and noise levels are shown through PSNR and IQI values in table.1. Comparison of these results show that the proposed method produces more detailed denoised images with all the distinct features and small structural details well preserved. Higher values of PSNR and IQI show that the proposed filter performs superior to the other denoising methods.

3.3. Evaluation on increasing the size of images

The images were obtained from the public database [10] whose sizes were given by the provider and the performance evaluation of denoised results for increased image sizes of the MRI brain corrupted by 30% of impulse noise respectively are shown in Fig.3. Similarly this can be extended to 90% and the results for this as well as web dataset images of different sizes and noise levels are shown through PSNR and IQI values in table.2. Comparison of these results show that with increase in image size, the PSNR and IQI decreases and the denoising performance of the filter deteriorates.

The denoising results obtained for the PET brain image of tumor pathology corrupted by 30% of impulse noise is shown in Fig.4. Similarly this can be extended to 90% and the results for this as well as web data set images [10] of different types and noise levels are shown through PSNR and IQI values in table.3. Comparison of PSNR and IQI values indicates increase in denoising performance compared with MRI and CT images. In the clinical PET/SPECT with tumor pathology, the filter preserves the major visual signature of the given pathology.

The denoising performance of Ultrasound fetus normal Brain image corrupted by 30%-90% of impulse noise is shown through PSNR and IQI values in table.4. Comparisons of these results show that denoising not only performs but preserves important details of the image required for clinical practice. Comparison of PSNR and IQI values indicates better denoising performance compared to MRI and CT images. When compared with the PET/SPECT imaging the denoising performance is poor with respect to PSNR and IQI values.

4. Discussion

In this paper we propose a novel filtering method for impulse noise removal by extending the method presented in [12] to medical images. This new method show a better performance of the algorithm with respect to increased noise compared with the algorithm presented in [12]. The results are objectively compared using the well-known PSNR and IQI measures. The results from this study clearly show that proposed algorithm can be used to reduce noise with no negative impact on subjective or objective quality measures. We find that a reduction in noise up to 80.0% is possible compared with the other studies [1–3] that have evaluated the use of Denoising algorithm for brain. Our finding is greater than that identified 60.1% reduction [4] and 56% reduction[15] in noise. For medical images, edge information is important for the diagnosis. The margin information characterizes tissue surrounding a tumor (mass). Margins were better defined and the patterns of enhancement could be used to further classify a lesion. Morphological filter with multiple structuring elements is widely used for removing noise and preserving the edges well and further enhancing the edge features [16]. The proposed OCS filter uses variable sized structuring elements of size (3x3,5x5,7x7) to enhance the edge features to enhance the edge features of anatomical information corrupted by impulse noise and improves the accuracy of diagnosis (normal or abnormal).

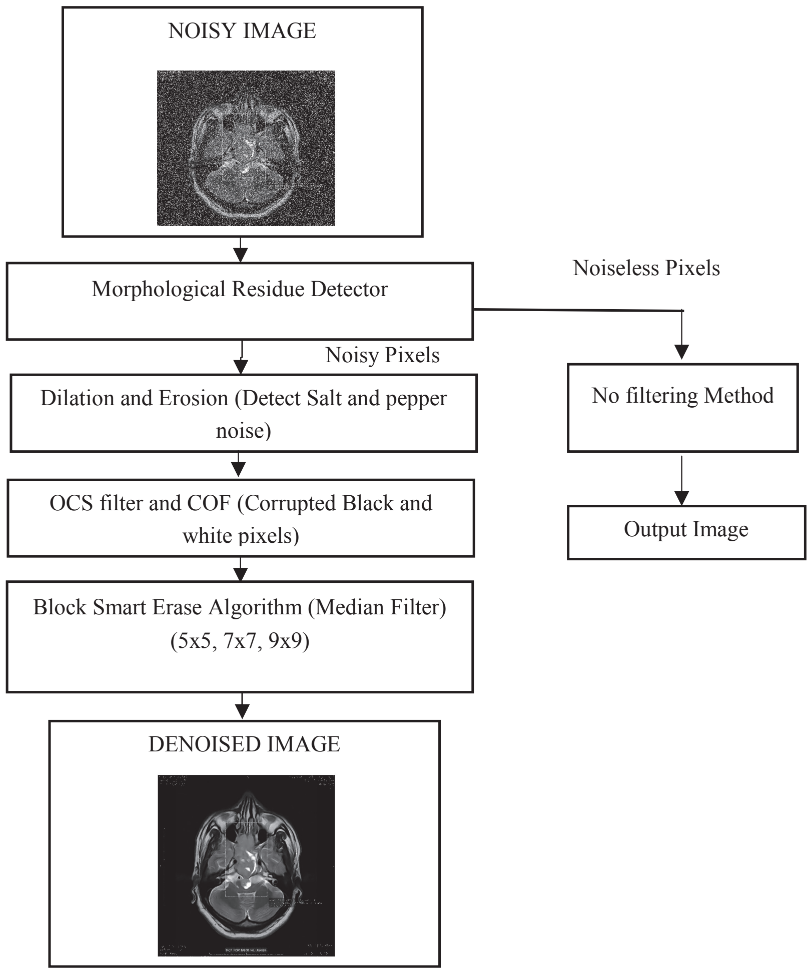
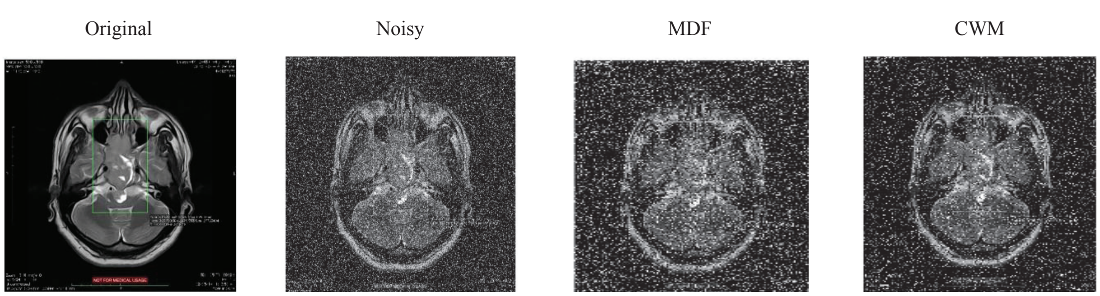


Fig.1. Proposed block diagram



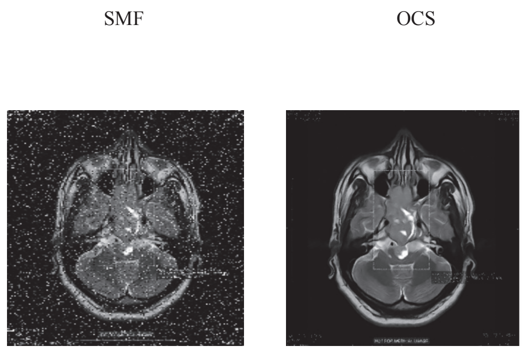


Fig.2. Restoration Results for T2 weighted axial MR brain image corrupted by 30% of impulse noise

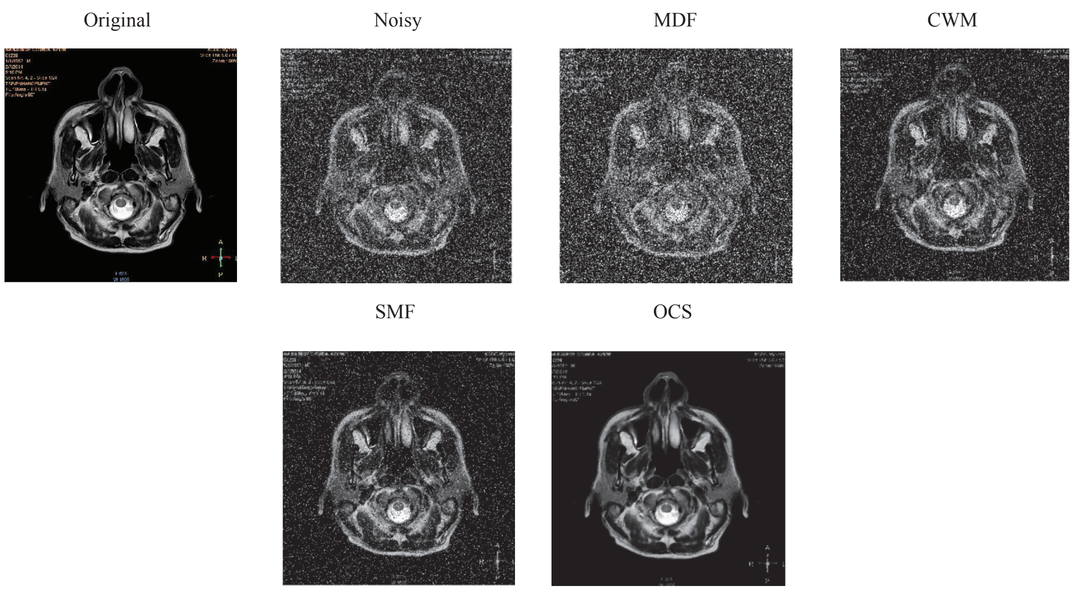


Fig.3. Restoration Results for MR brain image corrupted by 30% of Impulse noise with the image size of (560x560)

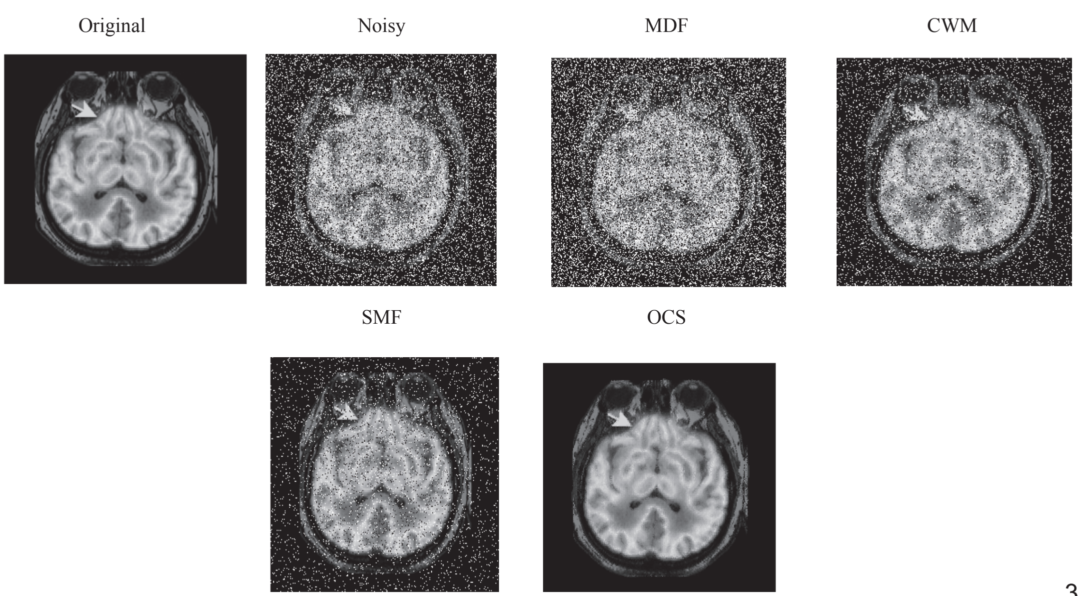


Fig.4. Restoration Results for PET Brain Image corrupted by 30% of Impulse noise

Table 1: Performance Parameters of MRI Brain Image (958x958) corrupted by Salt and Pepper noise.

Noise Variance	PSNR ratio in dB					
	MDF	AMF	CWM	DBA	SMF	OCS
30	16.21	18.12	20.13	21.66	22.55	23.11
40	15.16	17.21	18.88	19.16	21.21	22.57
50	14.23	15.16	17.21	18.26	20.16	22.31
60	13.16	14.17	15.06	17.09	19.34	21.66
70	12.21	13.22	14.87	16.26	18.22	20.76
80	10.06	12.21	13.21	15.27	17.69	19.26

Table 2: Performance Parameters of MRI Brain Image (560x560) corrupted by Salt and Pepper 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

Table 3: Performance Parameters of PET Brain Image (256x256) corrupted by Salt and Pepper noise**.**

Noise Variance	PSNR ratio in dB					
	MDF	AMF	CWM	DBA	SMF	OCS
10	25.51	28.13	30.16	33.26	35.51	34.53
20	22.59	24.27	26.21	29.41	30.61	33.87
30	20.43	22.17	24.55	28.36	30.01	32.09

40	19.33	21.31	23.21	27.26	27.27	29.25
50	17.16	19.17	21.13	26.55	25.12	27.46
60	15.56	17.12	19.19	23.52	24.66	26.56
70	13.43	15.26	17.26	20.26	21.21	24.57
80	11.51	14.13	16.51	18.13	20.55	22.36
90	9.16	13.12	15.26	16.12	19.12	21.52

Table 4: Performance Parameters of US Fetal Brain Image (320x320) corrupted by Salt and Pepper noise.

Noise Variance	PSNR ratio in dB					
	MDF	AMF	CWM	DBA	SMF	OCS
10	26.11	28.55	30.56	32.13	33.13	34.38
20	25.06	27.16	29.13	31.15	31.19	33.82
30	22.02	26.11	28.01	30.33	31.55	33.22
40	20.13	21.55	24.44	26.77	28.18	32.96
50	16.12	19.13	22.10	24.34	26.66	29.55
60	14.16	17.16	20.33	22.26	24.55	27.48
70	12.01	16.21	19.15	21.13	23.16	25.55
80	10.66	12.15	13.12	14.16	19.11	23.55
90	8.953	11.12	12.10	13.16	16.16	21.22

5. Conclusion

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 restoration scheme can be divided into two stages, identification and deletion of contaminated pixels and restoration of deleted pixel values. The drawback of proposed filter is, if the noise level increases beyond 80% 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. In future we want to deal with random valued impulse noise that appears in medical images.

Acknowledgement: This Research work has been carried out at the Medical Image analysis laboratory PES College of engineering, Mandya, Karnataka, India. The authors would like to acknowledge the financial support from VGST-K-FIST grants during 2015 for the establishment of the above laboratory.

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