Combined Bilateral and Anisotropic-Diffusion Filters for Medical Image De-noising

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***Abstract*—Image de-noising is a core operation in image processing and computer vision. In this paper, combination of two popular methods in image de-noising bilateral and anisotropic-diffusion filtering is investigated to reduce the noise in medical images, while preserving the clarity of images. The proposed method experimented on 23 MRI images. The results obtained from the proposed method gained higher peak signal to noise ratio (PSNR) and compression ratio (CR) performance in comparison with the traditional methods by more than 8%.**

Keywords: Image Denoising, Bilateral, Anisotropic- Diffusion, Combination Filters, Image Compression.

I. INTRODUCTION

Noise elimination or reduction is a fundamental process of reducing the effect of noise in deteriorated images, while keeping its structure and pertinent information intact. Noise can be introduced into the image in many ways during acquisition and transmission, affecting resolution, illumination and calibration.

Medical imaging is one of the most important tools in helping doctors with diagnosing patient status, treatment decisions and guiding surgeries. In medical imaging, the acquisition time is limited usually due to the condition and comfort of the patient. Therefore, faster imaging is demanded. However, faster acquisition speeds introduces more noise to the image, which degrades image quality and resolution, hides structural details and blurs edge boundaries. Thus, de-noising is a fundamental process in many medical image processing applications to 'clean' the images. De-noising techniques can be classified in two main domains, namely, spatial and transform. The spatial approach can be further categorized into two methods: linear and non-linear. Bilateral [1] and anisotropic-diffusion [2] filtering are two types of representative non-linear methods which are proven to be effective in removing noise while preserving the details. The transform de-noising approach in [3] is based on the Fourier transform and always loses the high frequency information.

In this paper, we investigate the implementation of bilateral and anisotropic-diffusion filters for medical image de-noising. Specifically, we propose a new framework for image de-noising based on a combination of these two filters. To the best of our knowledge, there is no other published work which combines bilateral and anisotropic-diffusion filters in the context of medical image de-noising.

This paper is organized as follows: In section II, we briefly describe the edge preserving and smoothing algorithms, and review their related works. In section III, we define our new model for edge preserving and image smoothing. In section IV, we present the experimental results of the new model. In section V, we conclude the paper.

II. LITERATURE REVIEW

In the last decade, there have been many research findings in de-noising techniques. According to [4], Gaussian filter has good performance in smoothing images, but loses some details. The kernel of the Gaussian method is optimal in flat regions but the edges and the textures are also blurred.

Bilateral filtering [5] is a non- iterative and local approach to edge-preserving smoothing. A filtered image is obtained by replacing the intensity value of each pixel with an average value weighted by the geometric and photometric similarities between neighboring pixels within a spatial window. The bilateral filter can be summarized using the following equation:

$$h(x) = k^{-1} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(\zeta)c(\zeta, x)s(f(\zeta), f(x))d\zeta \quad (1)$$

where

$$k(x) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} c(\zeta, x)f(f(\zeta), f(x))d\zeta \quad (2)$$

Bilateral filtering is a non-iterative method only if a wide spatial window is used (e.g. 915 pixels in each dimension)[6]. However, a wide spatial window many over-smooth sharp ridges and gutters in the image. It is necessary to strike a

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balance between the size of the window and the amount of details to be preserved.

Anisotropic-diffusion is one of the most popular techniques in image de-noising. The anisotropic-diffusion filter was introduced by Perona and Malik[7] and was able to establish a powerful tool for image enhancement. Anisotropic-diffusion depend on partial differential equation (PDE) to remove the noise from an image. The Perona–Malik equation is as follows:

$$I_t = div(c(x,y,t)\nabla I) = c(x,y,t)\Delta I + \nabla c.\nabla I \qquad (3)$$

where ***div*** is the divergence operator, Δ and ∇ are the Laplacian and the gradient operators respectively. I_t reduces to the isotropic heat diffusion equation $I_t = c\Delta I$ if $c(x,y,t)$ is constant.

The effectiveness of bilateral and anisotropic-diffusion filters encouraged researchers to combine these filters with other methods to further improve the performance of image de-noising. For example, the authors in [6] proposed a de-noising method, which combined bilateral filtering and wavelet thresholding. They applied the bilteral filter on the approximation subbands and wavelet thresholding on the detail subbands. The results indicate that this new framework was very effective in eliminating noise in real images.

Another method was based on the combination of bilateral filter and wavelet for de-noising of different types of images was applied in [7]. The model was evaluated based on the image quality index (IQI) and peak signal to noise ratio (PSNR). The experimental results showed that the effect of the bilateral filter before and after the decay due to the subbands of the decomposed image enhanced its performance.

In [8], a de-noising method based on a double bilateral filter with a median filter was inserted into the de-noising framework at the second bilateral filter improved the performance in restoring images degraded by the grouping of Gaussian and impulse noise.

Another simple but effective de-noising method, using double bilateral filtering was introduced in [9], where the first bilateral filter was used as a funnel and the second bilateral filter denoised the image. This method achieves enhanced performance compared to the traditional bilateral filtering method.

The authors in [10] modified a double bilateral filter for image noise removal by adding a 3 × 3 median-metric weighting function into a second bilateral filter. The proposed method differs from other nonlinear filters as it removes only the degraded pixel by the median value or by the neighbouring pixel value. The experimental results showed that the new method removed the noise effectively even at a high noise levels of 90% and preserved edges without any loss up to 80% noise level.

A new method to estimate the best bilateral filter intensity parameter set in the case of shot noise removal, the dominant form of natural noise in digital imaging was undertaken in [11]. They showed that it is important to adapt the level of filtering to the level of noise and how the bilateral filter could be optimised if the noise level is known. By applying this noise level detection method to set the bilateral filter parameter, they obtain a novel adaptive bilateral filter, which exhibits best of-class performance at all noise levels.

The authors in [12] proposed a novel interpolation framework in which de-noising and image sharpening methods are embedded. In the proposed framework, the image is first decomposed using the bilateral filter into the detail and base layers which represent the small and large scale features, respectively. The detail layer is adaptively smoothed to suppress the noise before interpolation and an edge-preserving interpolation method is applied to both layers. Finally, the high resolution image is obtained by combining the base and detail layers.

A combination between shock filter and anisotropic-diffusion for image de-noising and enhancement was proposed by the authors in [13]. The proposed method not only performs well in removing noise but also enhances edges and keeps more structural details of an image. The experimental results show that the proposed method is better than the original methods.

A new anisotropic-diffusion filter for de-noising low-signal-to-noise molecular images was proposed in [14]. They incorporate a median filter into the diffusion steps. These combined filters achieve much better noise suppression than the original methods.

The authors in [15] proposed this framework to evaluate the effect of different de-noising methods on computed tomography (CT). They combined Gaussian and Prewitt operators and anisotropic-diffusion filters. The experimental results showed that the proposed method increases the quality of the denoised images.

A new model for image de-noising was proposed in [16], combining curvelet shrinkage with non-linear anisotropic-diffusion filter. The experimental results show that the new method has good performance for image de-noising.

A statistical relationship between bilateral and anisptropic-diffusion was established in [17]. This relationship provided a numerical scheme of estimation process for edge preserving smoothing. The experimental results showed that the proposed method reduces the effect of noise and preserves the edge structure.

The authors in [18] employed the combination of a nonlinear diffusion and bilateral filtering to smooth the image and detect the edges. The experimental results showed that the proposed method is more accurate in reconstructing the original image from the de-noised image.

III. Methodology

Despite the numerous combination methods in the literature, the combination of bilateral and anisotropic-diffusion filters has not been explored in any experimental work. The previous experiments in [17-18] motivated us to investigate the performance of image denoising based on the combined bilateral and anisotropic-diffusion filters.

The proposed method is motivated by the performance of the bilateral filtering in edge preserving smoothing. The idea of using bilateral filtering is to join both range and domain filtering. Another reason for this combination is the ability of the anisotropic diffusion (Perona and Malik) in enhancing the image quality by reducing the noise while preserving the edges, further motivating the proposal of this method, as illustrated in Fig. 1.

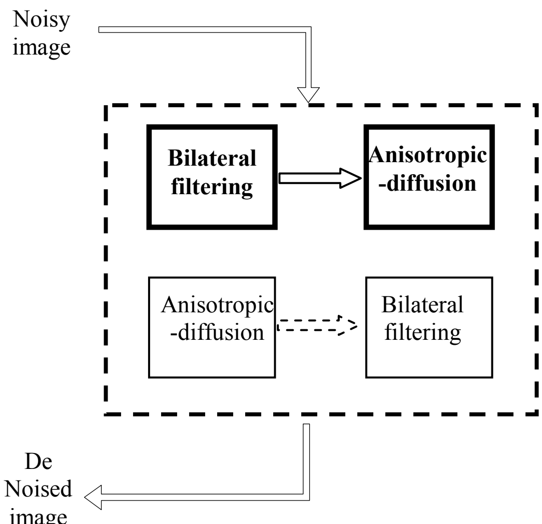


Fig.1.The framework of the proposed (in bold) and alternativemethods

In investigating the performance of the proposed method (*Bilat_Aniso*), comparison of the proposed method with the individual traditional methods would be undertaken by calculating the mean square error (MSE), the peak signal to noise ratio (PSNR) and the compression ratio (CR) for the original and denoised images. Then, the proposed method would be compared with the alternative combination (*Aniso_Bilat*) in Fig.1 to show that the performance of the combination method is dependent on the sequence of the combination.

IV. Performance Evaluation

We performed experiments on 23 MRI images to evaluate the validity of the new algorithm as mentioned above. Fig.2 shows two samples of MRI images used in the experiment.

The performance evaluation, in terms of PSNR and CR are tabulated in Tables 1 and 2 respectively. These measures are calculated using the following:

$$\mathrm{PSNR} = 10 \times log_{10}\left(\frac{1}{\mathrm{MSE}}\right) \tag{4}$$

where

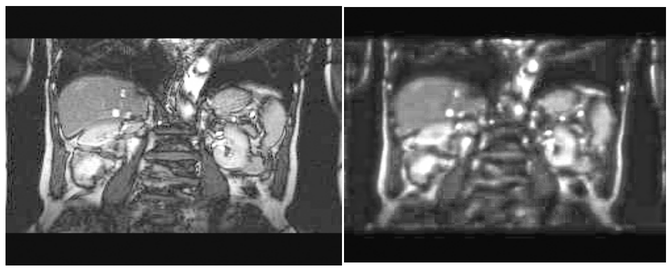
$$\mathrm{MSE} = \sqrt{\sum_{i=1}^{m}\sum_{j=1}^{n}(I(i,j) - I_0(i,j))^2/mn} \tag{5}$$

$$\mathrm{CR} = \frac{\mathrm{S_o}}{\mathrm{S_d}} \tag{6}$$

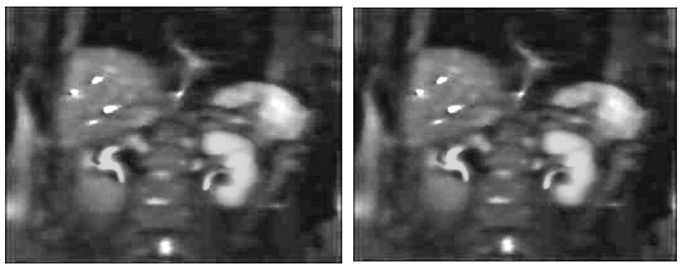
where

S_o = File size of the original image,

S_d = File size of the de-noised image.



(a)*Original* **(b)***Denoised*



(a)*Original* **(b)***Denoised*

Fig.2. Sample test of MRI images used and the corresponding denoised images generated using the proposed combination (*Bilat_Aniso*) filter.

Table 1: PSNR of the de-noised images using different methods

Image	Denoising methods			
	Anisotropic (dB)	*Bilateral (dB)*	*Proposed Method Bilat_Aniso (dB)*	*Aniso_Bilat (dB)*
308	37.59	36.98	42.77	35.24
309	36.17	36.11	40.54	34.21
310	37.43	36.88	42.83	35.45
311	36.41	36.29	41.28	34.62
312	37.59	37.64	41.98	35.4
313	35.12	35.86	39.01	33.20
314	35.40	36.57	38.55	33.45
315	35.44	35.82	39.88	33.43
316	36.16	36.80	40.00	33.83
317	33.91	35.45	36.94	32.28
318	35.23	36.20	38.88	33.19
319	34.73	35.89	38.37	32.84
320	35.50	36.60	39.07	33.48
321	34.44	35.88	37.73	32.53
322	36.35	37.62	39.78	34.20
323	34.55	35.98	38.23	32.53
324	36.14	36.90	39.83	33.90
110	34.93	35.46	32.02	40.54
111	31.91	34.17	29.62	35.97
112	32.75	34.55	30.25	36.95
113	33.03	34.53	30.46	37.53
114	32.32	34.19	29.91	36.26
115	33.74	34.62	30.94	38.71
Average	***35.08***	***35.96***	***39.20***	***32.91***

Table 1 illustrates the evaluation of average performance of 23 MRI clinical images in the JPEG format. The PSNR of proposed method (*Bilat_Aniso*) is higher than the other methods. In the proposed method of the combined filters improved PSNR by 9% and 11.74% as compared to single bilateral and anisotropic-diffusion filters respectively.

Similarly, the CR of the proposed method (*Bilat_Aniso*) is higher than the original methods, as tabulated in Table 2. It achieved higher CR by 8.79% and 26.92% as compared to single bilateral and anisotropic-diffusion filters, respectively. The alternative (*Aniso_Bilat*) achieved higher CR by sacrificing image quality, that is lower PSNR and this is not acceptable, especially in the case of medical images.

Table 2: CR of the de-noised images using different methods

Image	Denoising methods			
	Anisotropic	*Bilateral*	*Proposed Method Bilat_Aniso*	*Aniso_Bilat*
308	1.63	2.06	2.10	2.22
309	1.68	2.10	2.16	2.29
310	1.71	2.31	2.36	2.51
311	1.72	2.25	2.30	2.46
312	1.60	1.99	2.08	2.21
313	1.66	2.05	2.18	2.31
314	1.58	1.90	2.07	2.17
315	1.67	2.07	2.18	2.32
316	1.57	1.89	2.02	2.13
317	1.62	1.86	2.06	2.18
318	1.58	1.93	2.06	2.19
319	1.60	1.91	2.04	2.18
320	1.56	1.87	1.98	2.12
321	1.58	1.84	1.99	2.11
322	1.45	1.71	1.84	1.92
323	1.55	1.79	1.93	2.05
324	1.50	1.76	1.86	1.96
110	1.38	1.48	1.79	1.73
111	1.48	1.42	1.88	1.78
112	1.42	1.42	1.78	1.70
113	1.43	1.45	1.81	1.73
114	1.44	1.40	1.78	1.71
115	1.42	1.45	1.79	1.70
Average	***1.56***	***1.82***	***1.98***	***2.09***

V. CONCLUSION

In this paper, we have proposed new framework for image de-noising based on combined bilateral and anisotropic-diffusion filters. Our method (*Bilat_Aniso*) produces higher PSNR and CR by 9% and 8.79%, respectively. In future, we would like to implement the new method for other imaging modalities such as fluoroscopy and CT images.We also would like to adopt an image quality index for comparative measurements.

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