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A review on performance evaluation of anisotropic diffusion filter for denoising the speckle noise in retinal images

C.R.Dhivyaa[1], B.Gopinath[2]

[1]Assistant Professor, Department of CSE, Nandha College of Technology, Erode-638052

[2]Associate Professor, Department of ECE, Info Institute of Engineering, Coimbatore-641107

[1]crdhivyait@gmail.com, [2]gopiphd@yahoo.com

Abstract - *The performance of various filtering techniques has been analyzed and presented in this paper by targeting speckle noise in retinal images. Most of the state-of-the-art filters are trying to reduce the speckle noise effect from the images without considering the relevant information of blood vessel of retinal images. They also filter the significant features in the targeted images needed for the diagnosis purpose. In order to overcome the limitation of over filtering, the anisotropic diffusion filter is proposed to remove the speckle noise from the retinal image. The performance of the exiting filters and the proposed filter to remove the speckle noise in retinal images is evaluated in terms of the signal-to-noise ratio (SNR), Root Mean Square Error (RMSE) and Standard Deviation (SD) and compared. The experimental results show that the anisotropic diffusion filter is best suitable for removing speckle noise present in the retinal images.*

Keywords – Image filtering, Speckle noise, Retinal images, Speckle reduction, Image denoising

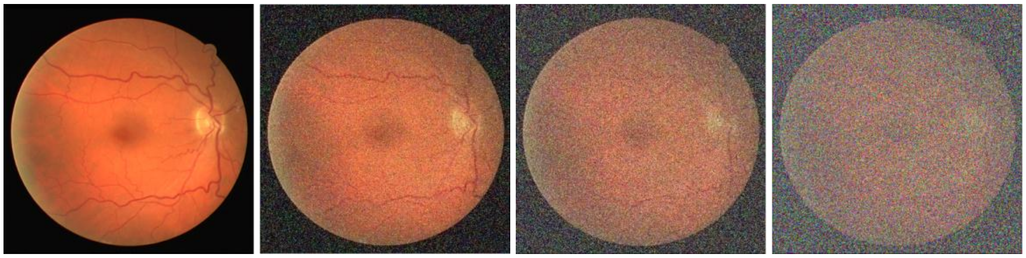
1. Introduction

The medical images are mostly useful to identify various kinds of diseases and also helpful in finding the severity levels of diseases .In medical imaging and analysis, the retinal imaging has rapidly grown in the field of ophthalmology. It primarily focuses on automated early detection of diabetic retinopathy (DR) from fundus retinal images.

For the reliable automated detection of diabetic retinopathy, the retinal images with high quality are required in various healthcare centers. Because of the noisy retinal images, the medical professionals are facing many problems among which incorrect diagnosis is a primary one. The images are corrupted by various kinds of noises in which speckle noise [12] is a complex phenomenon. It is a multiplicative noise that affects the edges and fine details of the target images which leads to degrade the image quality and hence it needs to be removed [5] for getting better performance in all aspects.

Denoisingby filtering is one of the widely used processes for removing the speckle noise from a noisy image. Several filtering techniques are available to reduce the noise level in an image. There are many denoising techniques that have been implemented to improve the quality of images. The median filter is one of the simplest filters used to remove the noise and smooth the images. Kenny KalVinToh in [25] proposed an efficient NAFSM(Noise adaptive fuzzy switching median) filter to remove the salt-and-pepper noise and Wei Fan et al. [4] developed a median filtering forensic method to enhance the image quality.Yuanxin Wu et al. [30] reviewed the Gaussian filters from the perspective of numerical integration and derived the ranking of accuracy of various Gaussian filters.Hui Kong in [13] proposed a model for detecting road-vanishing-pointbased on a new generalized Laplacian of Gaussian(gLoG) filter and this filter was applied to estimatethe texture orientation at each pixel of an image to detect vanishing point.

In this work,few promising filtering techniques have been implemented to reduce the noise and improve the quality of retinal images. The performances of all the filters have been compared in term of the statistical measures Signal-to-Noise Ratio, Root Mean Square Error and Standard Deviation.The study is organized as follows: Section 2 describes the speckle noise in retinal image and their characteristics. Section 3 elaborates the denoising techniques which include the filters to reduce the speckle noise in retinal images. Section 4 compares the performance of various filters and the work is concluded in Section 5.



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

Fig. 1. (a) Normal retinal digital fundus image (b) Image corrupted by 25% speckle noise (c) Image corrupted by 50% speckle noise (d) Image corrupted by 75% speckle noise

2. Speckle Noise

The speckle noise, commonly found in medical images, is a deterministic in nature and also occurs randomly. It mainly affects the edges of the blood vessels and local details between the blood vessels which are the most important parts for diagnosing the diabetic retinopathy disease. Fig.1.(a) showsthe normal retinal image while Fig.1.(b) (c) (d) shows the speckle noise added retinal image at three noise level variances 0.25, 0.5 and 0.75 respectively.

The general form of speckle noise is represented as,

$$g(n,m) = f(n,m) * u(n,m) + \varphi(n,m)(1)$$

Where *(n,m)*is the observed image,*u(n,m)* is the multiplicative component,*φ(n.m)* is the additive component of the speckles and *f(n,m)* is the actual image. Here *n* and *m* indicate the axial and lateral indices of the retinal image samples. Gregorio in [15] analyzed the effect of speckle noise in Ultra Sound (US) medical image using a novel parametric thresholding procedure.

In [5], Padmasiniperformedimage enhancement using fuzzification method and anisotropic diffusion filtering for effective reduction of speckle noise in SDOCT Retinal Images.NorashikinYahya et al. [8] proposed image-subspace based approach for removing the speckle noise from synthetic aperture radar (SAR) images and the proposed technique is based on linear estimator and reduced-rank subspace model to approximate the clean image from the affected one with speckle noise. An accelerated method was proposed by Carlos Trujillo et al. [14] that use general-purpose computing in graphics processing units to reduce the speckle noise. Itutilizesparallelized algorithms to record, reconstruct, and superimposemultiple uncorrelated holograms of a static scene.

3. Denoising Techniques

Denoising Technique is a process of removing noise from the corrupted image for improving the quality of an image which will be useful for further operations.

3.1 Median Filter

The median filter is a nonlinear filtering technique which works on the centre pixel means. It works by replacing each value within the median value of neighboring pixel. The window moves pixel by pixel, over the entire image and the median is calculated by neighboring pixel values. Kenny KalVinToh et al. [25] employed a median filter to detect and remove the salt-and-pepper noise from the image effectively. Keerthi Ram et al. [23] developed a median filter to obtain the background of an image for minimizing the effect of intensity variation in the background across the image. In this work, the median filter is applied to remove the speckle noise from the retinal image corrupted at various levels (25%, 50% and 75%).Here, the optimal sampling window size of median filter has been selected as*5x5*.

Let $x=(x_1, x_2 \ldots x_i \ldots x_n)$ denotes the image of n pixels, the i^{th} pixel of its median filtered value can be attained by:

$$y_i = median\ (P^i\, x)(2)$$

Where, P^iisa sparse matrix extracting the image block of size *5x5*.

3.2 Local Minimum Filter

Local Minimum Filter is a nonlinear 0^{th}percentile filter which helps to remove white noise from an image in which single white pixel is replaced by any one of its surrounding pixels with a smaller value. It is mainly used to reduce eyelash noiseswhich will be helpful to highlight blood vessels of the retinalimage. HaoYuanet al. [18] developed a best deterministic algorithm to compute minimum filters and experimented against the images. The local minimum filter has been applied to remove speckle noise from retinal image.It is used to remove the noise at various levels to check the performance of the filter. The local minimum filter is defined as $\varphi(F)$ and given in Eq. 3.

$$\varphi(F) = min\{f_{pq}; (p,q)\epsilon N(i,j)\} \quad for\ \forall(i,j)\epsilon\ I\ X\ I \qquad (3)$$

Where, *N (i, j)* is an arbitrary neighborhood of *(i, j)* and independent of *(i, j).*

3.3 Local Maximum Filter

TheLocal Maximum Filter is a nonlinear filter which reduces the dark noise from an image. A single dark pixel within the region is replaced by its surrounding pixels with a maximum value. Jinsooet al. [29] used local maximum filters for suppressing the shoots occurred in the luminance or color transient improvement. In this work, the local maximum filter has been applied against the retinal images for removing speckle noise from an image which is mainly used to detect edges of the blood vessels. The filter removes speckle noise degraded at various levels. The local maximum filter is defined as $\mu(F)$

$$\mu(F) = max\{f_{pq}; (p,q)\epsilon N(i,j)\} \quad for\ \forall(i,j)\epsilon\ I\ X\ I \qquad (4)$$

Where, *N (i, j)* is an arbitrary neighborhood of *(i, j)* and independent of *(i, j).*

3.4 Gaussian Filter

The Gaussian filter is a linear smoothing filter with the weights chosenaccording to the shape of a Gaussian function. It performs a weighted average of surrounding pixels based on the Gaussian distribution. It removes sharp edges and does not have higher frequencies. It removes blurred edges and smoothes images. For image processing, the two-dimensional Gaussianfunction is given by,

$$g[i,j] = e^{-\frac{(i^2+j^2)}{2\sigma^2}} \quad (5)$$

Where, the Gaussian parameter σ determines the width of the Gaussian.MengqiuWanget al. [3] developed Gaussian filter to suppress the noise and obtain coherent features. These features are used to extract oil slick features from VIIRS nighttime images and other noisy remote sensing images. In this work, the Gaussian filter is used to remove speckle noise from the retinal image for improving the contrast of the image to detect blood vessels. The filter can be tuned by changing the value of sigma parameter. To obtain the optimal results, the sigma parameter value has been selected as 1. The speckle noise at various levels is removed by using this filter

3.5Laplacian of Gaussian Filter (LOG)

The Laplacian of Gaussian filter (LOG) uses a Gaussian blur and applies Laplacian filter to reduce the noise in an image. The filter can be adjusted by varying the value of sigma parameter which is used to remove the noise for extracting the edges of the blood vessels. In this work, an optimal smaller sigma value (σ=1) has been used to reduce speckle noise from retinal image degraded at various levels. The 2-D LoG function centered on zero and with Gaussian standard deviation is obtained as

$$LoG(x,y) = -\frac{1}{\Pi\sigma^4}\left[1 - \frac{x^2+y^2}{2\sigma^2}\right]e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (6)$$

Chia-Te Chou et al. [26] designed a LOG filter to extract edge-type maps for characterizing iris patterns in iris segmentation. In [13] Hui Kong developed a gLoG filter to estimate the texture orientation at each pixel of an image.

3.6 Bartlett Filter

Bartlett filter is as triangle shaped filter which is known as ‘tent’ filter. The filter is defined either by taking the product of two box filters or convolving two box filters. It filters high frequencies and smoothes the image which provides better quality images. The coefficients of a Bartlett filter are computed as follows:

$$w(x) = \begin{cases} \frac{2n}{N}, & 0 \le n \le \frac{N}{2} \\ 2 - \frac{2n}{N}, & \frac{N}{2} \le n \le N \end{cases} \qquad (7)$$

Where, *L* represents window length *(N+1)*. The triangular window is the second order B-spline window.Itcan be seen as the convolution of two *N/2* widthrectangular windows. EbtihalHaiderGismallaetal. [16]obtained accurate performance analysis of energy detection using Bartlett’s estimate as a test statistic. This filter with *5x5* window size has been used to remove the speckle noise from the image corrupted at various levels.

4. Proposed FilteringMethod for Denoising in Retinal Images

In this work, the anisotropic diffusion filter has been proposed with memory based speckle statistics for reducing the speckle noise present in the retinal images.

4.1 Anisotropic Diffusion filter with memory based speckle statistics

Anisotropic diffusion filter is a technique to reduce the noise from the retinal image without removing the salient parts of the retinal image content such as edges, lines and other details that are significant for the diagnosis of the Diabetic Retinopathy. It applies the law of diffusion on pixel intensities of retinal image to smooth textures. It uses a threshold functionto prevent diffusion to happen across edges so that the significant edges can be preserved in an image.Diffusion techniques in image filtering are based on the well-known diffusion equations is the following:

$$\frac{\partial u(x,t)}{\partial t} = \nabla.(L(x,t)\nabla u(x,t))(8)$$

$$\frac{\partial L(x,t)}{\partial t} = \frac{1}{\tau(x)}(L(x,t) - s\{D(x,t)\})(9)$$

Gabriel Ramos-Llordénet al. [6] proposed an anisotropic diffusion filter with a probabilistic-drivenmemory mechanism to overcome the over-filtering problem bytissue selective philosophy. In this work, the anisotropic diffusion filter has been applied to retinal image degraded by speckle noise at various levels.

5. Estimation of Statistical Parameters

The performance comparison of filters under the study has been carried out based on the statistical parameters Signal-to-Noise Ratio (SNR), Root Mean Square Error (RMSE) and Standard Deviation (SD).

SNR is a statistical measure which compares the level of desired signal to the level of background noise for finding the ratio of power of signal to power of noise and it can be computed as

$$SNR = 10\log_{10}\left[\frac{\sum_0^{n_x-1}\sum_0^{n_y-1}[r(x,y)]^2}{\sum_0^{n_x-1}\sum_0^{n_y-1}[r(x,y)-t(x,y)]^2}\right] \qquad (10)$$

Where, reference image is *r(x,y)* and *t(x,y)* is a test image. It compares the reference image *r(x,y)* with the test *t(x,y)*. The two images should have the same size *[nx, ny]*. If the value of SNR is very high for an image of a specific noise type then that image is the best quality image.

RMSEis a regularly used measure of standard deviation of the differences between predicted values and observed values. RMSE is computed by

$$RMSE = \sqrt{\frac{1}{n_x n_y}.\sum_0^{n_x-1}\sum_0^{n_y-1}[r(x,y) - t(x,y)]^2}(11)$$

Where, reference image is *r(x,y)*, test image is *t(x,y)* and image size is *[nx, ny]*. The value of *RMSE* is low for the best quality image.

The Standard Deviationis a measure which is used to quantify the amount of variation in degraded image. It is defined as square root of variance and isgiven in Eq. 12. The lowest standard deviationrepresents the best quality image.

$$SD = \frac{1}{N-1}\sum_{i=0}^{N-1}(x_i - \mu)^2(12)$$

Where, the image is stored in x_i, μ is mean value and *N* is the number of samples.

6. Results and Discussion

In this work, the process of denoisinghas been carried out for the retinal images with speckle noise of various levels (25%, 50% and 75%) using the existing and proposed filtering techniques. The performances of the filters are evaluated using statistical measures Signal-to-Noise Ratio, Root Mean Square Error and Standard Deviation. The performance of proposed technique is compared with the state-of-the-art filters as given in Tables 1, 2, 3 respectively.

Table 1 compares the statistical measurements of various filters for the retinal image corrupted by 25% of speckle noise.

Table 1.Image Quality Measures for Speckle noise (25%)

Filters	SNR	RMSE	SD
Median	6.27	9.43	96
Local Minimum	-2.18	10.7	34
Local Maximum	-4.08	9.43	29
Gaussian	4.44	7.12	75
LOG	-35.30	6.08	56
Bartlett	-35.69	1.61	73
Proposed Filter	4.49	1.57	62

The statistical measurements of the various filters for the retinal image corrupted by 50% of speckle noise are analyzed and compared as given in Table 2.

Table 2.Image Quality Measures for Speckle noise (50%)

Filters	SNR	RMSE	SD
Median	3.69	4.56	86
Local Minimum	-1.47	11.36	17
Local Maximum	-8	9.64	16
Gaussian	6.94	7.58	53
LOG	-39.67	6.48	70
Bartlett	-40.17	1.822	51
Proposed Filter	3.74	1.4	57

The comparison of statistical measurements of different filters for Retinal image corrupted by 75% speckle noise is given in Table 3. The proposed system produces better performance and it avoids over filtering by retaining the useful information in the retinal images.

Table 3.Image Quality Measures for Speckle noise (75%)

Filters	SNR	RMSE	SD
Median	3.34	3.73	47
Local Minimum	-9.77	7.85	11
Local Maximum	1.418	11.6	12
Gaussian	6.04	8.65	33
LOG	-42.96	6.63	76
Bartlett	-43.99	1.9	30
Proposed Filter	3.50	1.1	51

Table 4 compares the statistical measurements of proposed filter for the retinal image corrupted by 25%, 50%, and 75% of speckle noise.

Table 4.Image Quality Measures for Speckle noise (25%, 50%, and 75%)

Proposed Filter	SNR	RMSE	SD
25 % speckle noise	4.49	1.57	62
50 % speckle noise	3.74	1.4	57
75 % speckle noise	3.50	1.1	51

7.CONCLUSION

In this paper, various existing filters and proposed anisotropic diffusion filtering techniques were applied on the retinal image degraded by the speckle noise at 3 different levels 25%, 50%, 75% respectively and the performance of the filters has been analyzed by using three statistical measurements such as SNR, RMSE, SD. The proposed filter achieves better results in terms ofSNR, RMSE and SD measures.For the retinal image corrupted by 25% of speckle noise, the Standard Deviation (SD) andSignal-to-Noise Ratio (SNR) measures have not been reached expected value but the proposed filter has produced moderate values for each measures and the Root Mean Square Error (RMSE) has been improved. From the experimental results and performance analysis, it is observed that the proposed anisotropic filter preserves and enhances the vessel information that may be and also it is best suitable to remove the speckle noise present in the retinal images.

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