International Journal of Applied Information Systems (IJAIS) – ISSN : 2249-0868
Foundation of Computer Science FCS, New York, USA
International Conference on Communication Computing & Virtualization 2016

Medical Image Denoising using Rotated Wavelet Filter and Bilateral Filter

Kirti V. Thakur
College of Engineering,Pune
Shivajinagar ,Pune
Pin code-411005

Pramod G. Ambhore
College of Engineering,Pune
Shivajinagar ,Pune
Pin code-411005

Ashok M.Sapkal
College of Engineering,Pune
Shivajinagar ,Pune
Pin code-411005

ABSTRACT
This paper, is extension of author's earlier work in which use of rotated wavelet filters for image denoising was proposed. Here authors proposed new algorithm based on rotated wavelet filters and bilateral filtering. Proposed Algorithm is tested on different digital modalities (X-ray and Ultrasound) and compared with earlier work and found significant improvements in terms of quality metrics PSNR and SSIM. Implementation simplicity is beauty of proposed algorithm.

General Terms
Medical image denoising, Rotated wavelet filters, Bilateral filter.

Keywords
Image denoising, Rotated wavelet filters, Bilateral filter, PSNR, SSIM.

1. INTRODUCTION
Earlier medical field was far away from digital technology i.e. engineering field. But gradually this picture is changed and today both fields goes hand in hand. Most of the disease identification is based on digital imaging systems also known as digital modalities. These modalities include Ultrasonography, X-ray imaging, MRI scan, CT-scan etc. Due to digital imaging technology, disease identification at early stage is possible for doctors/physicians so that they can start appropriate treatment. But benefits of digital modalities sometimes limited by image noise. This noise may hamper quality of image and ultimately decision making. To overcome this limitation of image noise various methods are proposed by researchers. These methods are broadly classified as spatial domain, transform domain and hybrid domain methods. They have their own advantages and limitations. In this paper authors proposed algorithm based on hybrid domain approach. To develop this proposed algorithm rigorous literature review is done but only relevant literature papers are mentioned below.

In reference [6], author proposed spatial domain bilateral filtering in their paper. The non-iterative nature and simple implementation along with edge preservation ability are few features of this algorithm. This algorithm is one of the current state of art algorithm. In the reference [1] author proposed wavelet based image denoising. Further this work was modified in reference [3] according to threshold in which Stain Unbiased Risk Estimator (SURE) is used. Authors in reference [7] claim that application of spatial domain bilateral filter for approximate band will remove additional low frequency noise from images and they named this concept as multiresolution bilateral filtering. In year 2000, Kim and Udpa [2] introduced the rotated version of wavelet transform and named it as Rotated Wavelet Filters (RWF). Their goal to design these filters is to separate mixed diagonal information which was hampering feature selection ability in texture classification application. Authors in [10] are motivated from RWF [2] and proved that RWF are also useful in the application of image denoising. They proposed simple energy test for testing suitability of RWF in the existing wavelet based image denoising algorithm. Wavelet transform has limitation of less directionality or in other words it has less directional selectivity which is very important from image denoising point of view. Kingsbury et.al. [4] gives solution to overcome above stated limitation. They derived six orientations along with two approximate bands in their paper and named it as Dual Tree Discrete Wavelet Transform (DTDWT). Authors [5] took advantage of RWF proposed in [2] and suggest combine use of DTDWT and Rotated DTDWT (RDTDWT) for increasing directionality. In reference [8], combination of Contourlet transform and bilateral filtering is suggested. As Contourlet transform is advantageous over wavelet transform, combination of Contourlet transform and bilateral filtering gives better results than multiresolution bilateral filtering On similar line, recently Digital Shearlet transform is proposed in [11]. Its superiority than earlier transforms is proved in their paper. Based on this researcher in [9] suggest hybrid algorithm for image denoising using bilateral filtering and Shearlet transform. Normally in transform domain, denoising algorithms consider detailed sub bands for noise removal. Approximate band is kept untouched most of the times. But from references [7,8 and 9], we understood that additional filtering in approximate band results into better performance. This gives rise to authors proposed work.

The remaining sections are organized as section 2 ,3,4 and 5. In section 2, basic theory of rotated wavelet filters and bilateral filters is described in brief. Proposed hybrid method is mentioned in section 3. Detailed discussion and experimentation is given in section 4 and section 5 is conclusions and future scope of the topic.

2. BILATERAL FILTER AND ROTATED WAVELET FILTER THEORY
Bilateral filter: Spatial domain filtering is blessed with some state of art denoising techniques such as Nonlocal means filtering [12], Block matching and 3D filtering (BM3D) [13], Bilateral filtering [6] etc. Out of this bilateral filtering is favorite due to non-iterative nature and edge preserving ability. Bilateral filtering considers two types of distances namely photometric distance and geometric distance. This distances are calculated using following equations 1 and 2.

$BF[I_x] = W^{-1} * \sum [W_g(\in, x)*W_p(\in,x) *I_q]$ (1)

where, $W= \sum (W_g(\in, x)*W_p(\in,x))$

$W_g(\in, x)$ = geometric weight between center x and local window ∈. Similarly, $W_p(\in, x)$=photometric weight between center x and local window∈ and I_q=Intensity of noisy pixel. Bilateral filter performance mainly depends on two input parameters, σ_d and σ_r. These two parameters are useful in geometric weight and photometric weight calculation. Selection of parameters is very crucial job in bilateral filtering.

Rotated wavelet filters: Rotated wavelet filters were developed in the year 2000 by Kim and Udpa for texture classification purpose. First step to design these RWF is conversion of one dimensional impulse response of low pass and high pass filter into two dimensional array. Then this 2D array is rotated by 45 ° to get rotated response of filters. Equations (2 to 5) for generating 2D impulse response are as follows: -

H_{LL} = [1D-LPF] ^{T} *[1D-LPF] … (2)

H_{LH} = [1D-LPF] ^{T}*[1D-HPF] … (3)

H_{HL} = [1D-HPF] ^{T}*[1D-LPF] … (4)

H_{HH} = [1D-HPF] ^{T}*[1D-HPF] … (5)

Detailed explanation /design is given in reference [10]. Dimensions of this rotated filters are different than 1D/ 2D filters and calculated as given below in equation (6)

[M, N] = (2S-1) x (2S-1) … (6)

where S = the 1-D filter size. M= Maximum no. of rows for rotated filter and N= maximum no. of column for rotated filter.

This new set of impulse response gives separation of mixed diagonal information. Combination of rotated wavelet filter and bilateral filtering is soul of proposed algorithm. Proposed algorithm is explained in next section.

On similar line rotated dual tree discrete wavelet transform is designed [10] and implementation of proposed work is done. Proposed work is explained in detail in the next section.

3. PROPOSED ALGORITHM

In this paper, authors proposed hybrid method to improve the performance of their earlier work. They have proposed two algorithms here.

Algorithm 1 is proposed to improve the performance of Rotated wavelet filters [10] for image denoising application. Combination of RWF and bilateral filtering is proposed. Steps for algorithm 1 are listed below-

(i) First design rotated wavelet filters (RWF) (refer [10]).

(ii) Perform Energy testusing equation (7).

$$\text{Energy=E=}\sum_{i,j=1}^{l} Mod(W(i,j))\text{^}2 \quad (7)$$

Where W(i,j) = wavelet/rotated wavelet coefficients (refer [10])

(iii) Once the test is passed, apply bilateral filter to approximate band of RWF decomposition.

(iv) Apply thresholding [3] to detailed bands of RWF decomposition.

(v) Reconstruct image from modified sub bands of RWF.

(vi) Measure the quality metric PSNR and SSIM of noisy and denoised image.

Following figure 1 depicts block diagram of proposed algorithm1 for rotated wavelet filters. Again for algorithm 2 RDTDWT strategy is little bit different. Pre and post processing with bilateral filtering is suggested for RDTDWT instead of filtering two approximate bands of RDTDWT. This is shown in figure 2. Use of bilateral filter is modification and indicated with yellow color text in both diagrams. Algorithmic steps for algorithm 2 are given below.

Steps for algorithm 2-

(i) Apply bilateral filter to noisy input image as preprocessing step.

(ii) Design of RDTDWT (refer [10]).

(iii) Perform Energy test (refer [10]) on preprocessed image.

(iv) Once the test is passed, apply thresholding [3] to detailed bands of RDTDWT decomposition.

(v) Reconstruct image from modified sub bands of RDTDWT.

(vi) For post processing use bilateral filter on reconstructed image.

(vii) Measure the quality metric PSNR and SSIM of noisy and denoised image.

Quality Measures:

Peak Signal to Noise Ratio (PSNR), Mean Squared Error (MSE), and SSIM etc are used as image quality measures. Authors used PSNR as quality measure. To calculate PSNR, MSE is required.

Mean Square Error (MSE):

The Mean squared error (MSE) is used to measures the average absolute difference between two images. It can be mathematically represented as per equation (8) given below

$$MSE = \frac{1}{M*N} \sum_{j=1}^{\text{Last row}} \sum_{k=1}^{\text{Last Column}} (X_{j,k} - X_{j,k'})^2 \quad (8)$$

Where M=No. of Rows and N=No. of Columns

Peak Signal to Noise Ratio (PSNR):

The ratio between possible power of a signal and the power of corrupting noise that affects the quality of image is nothing but the Peak Signal to noise ratio. Quality of the denoised image is directly proportional to the Peak Signal to noise ratio i.e. Higher PSNR value provides higher image quality. It is represented as given below,

$$PSNR=20*\log_{10} \frac{(2^b-1)}{\text{Mean Square Error}} \quad (9)$$

Where b= no. of bits.

SSIM:

The similarity between denoised image and noisy image is represented by a quality metrics called as structural similarity index. SSIM is define as per equation (10).

International Journal of Applied Information Systems (IJAIS) – ISSN : 2249-0868
Foundation of Computer Science FCS, New York, USA
International Conference on Communication Computing & Virtualization 2016

$$\boldsymbol{SSIM(m,n)} = \frac{(2*\boldsymbol{Mean_m}\,\boldsymbol{Mean_n} + \boldsymbol{d_1})(\boldsymbol{2Var_{mn}} + d2)}{(\boldsymbol{Mean_m^2} + \boldsymbol{Mean_n^2} + \boldsymbol{d1})(\boldsymbol{Var_m^2} + \boldsymbol{Var_n^2} + \boldsymbol{d_2})} \quad (10)$$

Where $\boldsymbol{Mean_m}$ = average value of original image, $\boldsymbol{Mean_n}$ = average value of denoised image

$\boldsymbol{Var_m^2}$= Original image variance,$\boldsymbol{Var_n^2}$ = Denoised image variance,$\boldsymbol{Var_{mn}}$ = Covariance of original and denoised image.

$$\boldsymbol{d_1} = (\boldsymbol{k_1}\,\boldsymbol{D})^2 \;, d2 = (\boldsymbol{k_2}\,\boldsymbol{D})^2$$

D= Image Range or dynamic range

$$\boldsymbol{k_1 = 0.01 \; and \; k_2 = 0.03 \; by \; default}$$

4. EXPERIMENTATION AND DISCUSSION

MATLAB 13a environment is used for implementation of proposed work. Proposed work is tested on general, ultrasound and X-ray images. PSNR and SSIM quality metrics are used for result comparison. Two separate tables, table1 and 2 are given below for comparison of algorithm 1 and 2. Table 1 is dedicated for performance evaluation of proposed algorithm 1 with existing work [10] and table 2 is indicating performance of RDTDWT and two stage Bilateral filtering (algorithm 2) with RDTDWT [10].

Table 1. Comparison between RWF [10] results and proposed algorithm 1.

Image type	**RWF [10]**		**Proposed method (BF_RDWF)**	
General	**PSNR (DB)**	**SSIM**	**PSNR (DB)**	**SSIM**
Barbara	28.4138	0.789331	29.1100	0.8117
Lena	29.7569	0.789294	29.2739	0.7599
Boat	28.6879	0.781616	28.3392	0.7493
Ultrasound				
s1.png	31.8272	0.905666	33.1728	0.9451
s3.png	29.5135	0.768121	30.1826	0.8528
X-ray				
1.tif	30.5303	0.764739	32.6306	0.8909
2.tif	29.9993	0.751368	31.8677	0.8855
3.tif	31.1805	0.823257	31.8370	0.8952

From above table 1, it is observed that both quality metrics are improved compared to earlier method [10]. Additional bilateral filtering to approximate band removes additional noise from low frequency components hence PSNR and SSIM improvement is observed here.

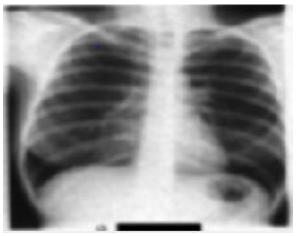
Table 2. Comparison between RDTDWT results and proposed algorithm.

Image type	**RDTDWT [10]**		**Proposed method (2_BF_RDTDWT)**	
General	**PSNR (DB)**	**SSIM**	**PSNR (DB)**	**SSIM**
Barbara	32.6057	0.9676	34.2015	0.9809
Lena	32.3133	0.9703	34.5861	0.9803
Boat	31.3094	0.9715	33.2510	0.9715
Ultrasound				
s1.png	31.4904	0.9016	34.50510	0.9754
s3.png	28.5546	0.8505	33.7651	0.9693
X-ray				
1.tif	31.1616	0.8794	33.8162	0.9864
2.tif	29.9845	0.8451	31.3999	0.9841
3.tif	30.6719	0.9304	32.3357	0.9818

Above table 2 depicts that two stage bilateral filtering enhances the performance of independent RDTDWT algorithm drastically. In case of RDTDWT, two approximate band are present. So twice use of bilateral filter comes into picture. Authors experimented and found that instead of using bilateral filter for two approximate bands pre and post filtering approach is more appropriate. Visible results of pre and post filtering approach and algorithm 1 are depicted below in figure 3.

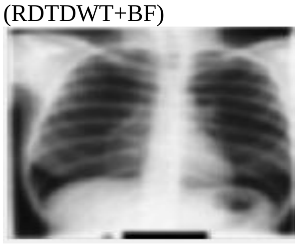
Visible results for Algorithm 2:

Noisy Image



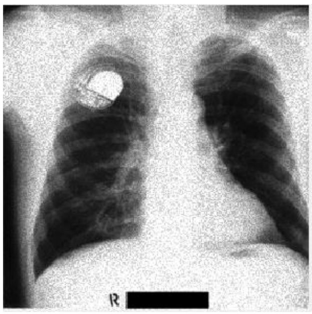
[PSNR= 24.98db]

Denoised Image (RDTDWT+BF)



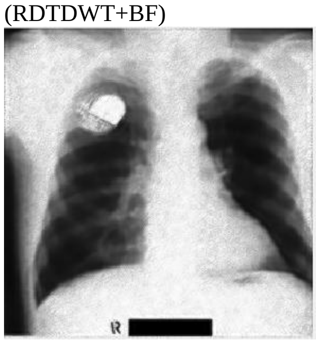
[PSNR=32.33db]

Noisy Image



[PSNR= 29.07db]

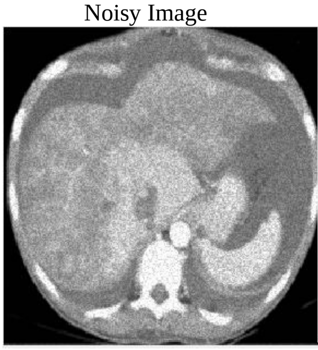
Denoised Image (RDTDWT+BF)



[PSNR=31.86db]

Visible results for Algorithm 1:

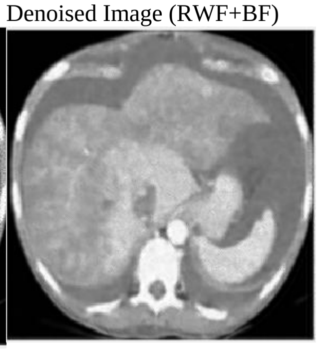
Noisy Image



[PSNR= 25.03db]

Noisy Image

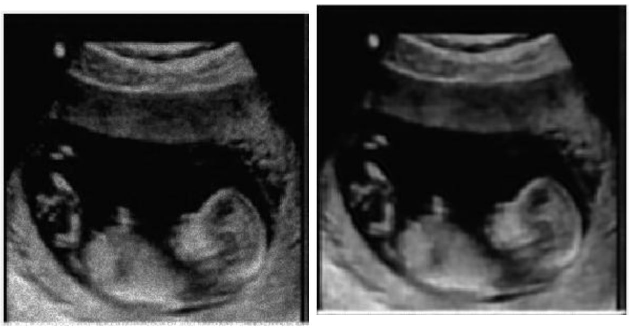
Denoised Image (RWF+BF)



[PSNR=30.18db]

Denoised Image(RWF+BF)

International Journal of Applied Information Systems (IJAIS) – ISSN : 2249-0868
Foundation of Computer Science FCS, New York, USA
International Conference on Communication Computing & Virtualization 2016



[PSNR= 30.72 db] [PSNR= 33.17db]

Fig.3 Visible results of proposed algorithm 1 and 2.

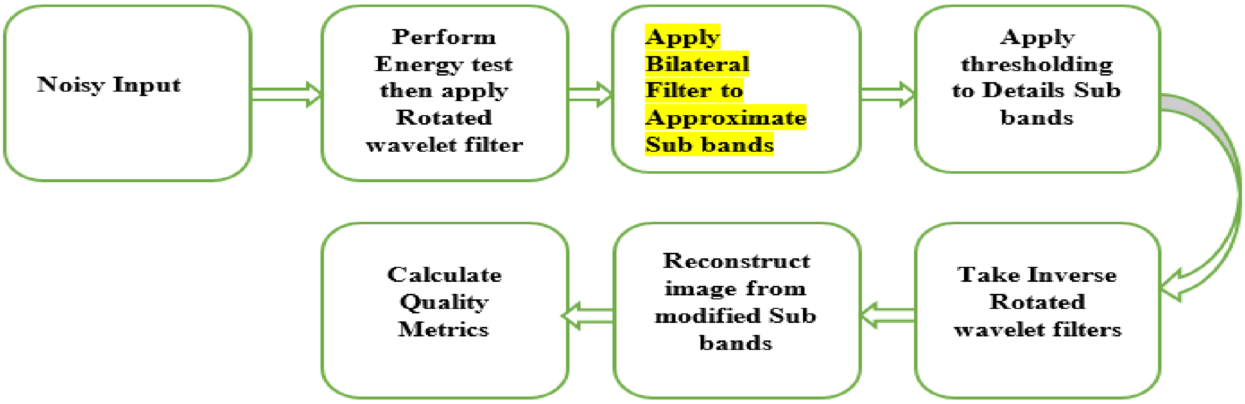


Fig 1: Block diagram for proposed algorithm 1 (RWF and Bilateral filtering)

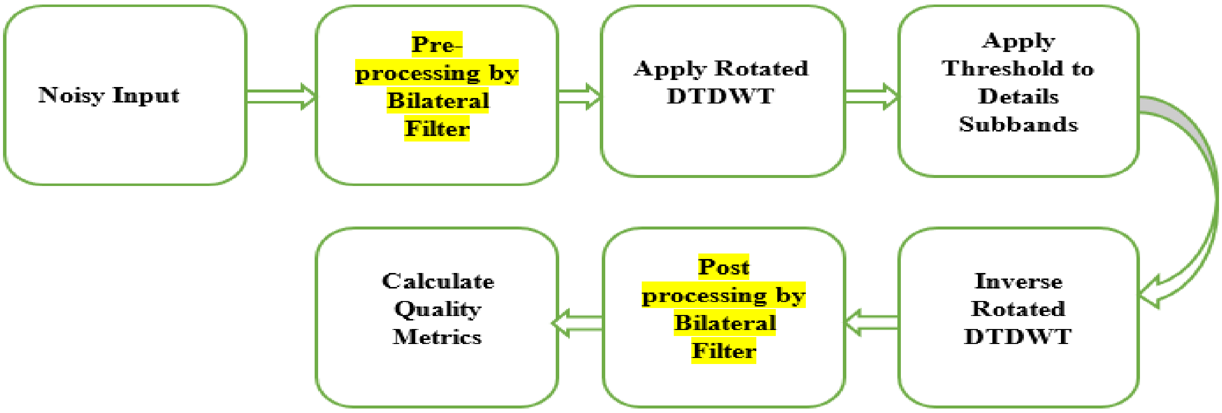


Fig 2: Block diagram of proposed algorithm 2 (pre and post bilateral filtering and RDTDWT)

5. CONCLUSIONS AND FUTURE SCOPE

This paper suggests hybrid approach for image denoising. Bilateral filter has proved its dominance in spatial domain. Engagement of bilateral filter with rotated wavelet filter and Rotated dual tree wavelet filter enrich the performance of transform domain algorithms. This is proved experimentally in this paper.

Modifications in bilateral filter according to noise type is future scope of this topic.

6. ACKNOWLEDGMENTS

We would like to acknowledge the support of faculty member from College of Engineering, Pune who have contributed their valuable inputs timely.

7. REFERENCES

[1] D.L. Donoho,' De-noising by soft thresholding', IEEE Trans. Info. Theory 1993, 43, pp. 933- 936.

[2] Nam-Deuk Kim and Satish Udpa,'Texture Classification using Rotated Wavelet Filters' IEEE Trans.Systems,Man and Cybernetics – Part A: November 2000,vol.30,N0.6. pp.847-852.

[3] F. Luisier, and et al, ’A new SURE approach to image denoising: Inter-scale orthonormal wavelet thresholding’, IEEE Trans. Image Process., Mar. 2007, vol. 16, no. 3, pp. 593–606.

[4] Ivan W. Selesnick, Richard G. Baranuik, and Nick G. Kingsbury,’ The Dual Tree Complex Wavelet Transform’, Nov. 2005 IEEE, Signal Proc. Mag.

[5] K.V.Thakur, and et al ,’A combined approach for noise reduction in medical images using dual tree discrete wavelet transform and rotated dual tree discrete wavelet transform’, IEEE international conference on Industrial Instrumentation and Control (ICIC)2015,28-30 May 2015,pp.1003-1008.

[6] C. Tomasi, R. Manduchi, ‘Bilateral filtering for gray and color images’, Sixth International Conference on Computer Vision,pages 839-846, 1998

[7] Ming Zhang and Bahadir K. Gunturk, ‘Multiresolution Bilateral Filtering for Image Denoising’, IEEE Transaction on Image Processing, Vol. 17, No. 12, December 2008

[8] C.J. Li, H.X. Yang, Y.Y. Cai and B. Song, ‘Image Denoising Algorithm Based on Non-Subsampled Contourlet Transform and Bilateral Filtering’, International Conference on Computer Information Systems and Industrial Applications, 2015

[9] K.V.Thakur, O.H. Damodare and A.M. Sapkal,'Hybrid method for medical image denoising using Shearlet transform and Bilateral filter', International Conference on Information Processing (ICIP),IEEE conference held at Pune in Dec. 2015

[10] K.V.Thakur, P.G. Ambhore and A.M. Sapkal,'Novel Technique for Performance Improvement of the Wavelet Based Denoising Algorithms Using Rotated Wavelet Filters', International Conference on Communication ,Computing and Virtualization (ICCCV-2016),Elsevier conference will held at Mumbai in Feb. 2016

[11] Wang-Q Lim, 'The Discrete Shearlet Transform: A New Directional Transform and Compactly Supported Shearlet Frames',IEEE transactions on Image Processing,Vol. 19, No. 5, May 2010.

[12] A.Buades, B.Coll,J.M. Morel,' A non-local algorithm for image denoising,' IEEE Computer society conference on computer vision and pattern recognition,Vol.2,pages 60-65,2005.

[13] K. Dabov, A. Foi, V. Katkovnik, and K. Egiazarian, ‘Image denoising with block-matching and 3D filtering’, Proc. SPIE Electronic Imaging '06, no. 6064A-30, San Jose, California, USA, January 2006.

[14] Z. Wang, A. C. Bovik, H. R. Sheikh and E. P. Simoncelli,’Image Quality Assessment: From Error Visibility to Structural Similarity’, IEEE Transactions On Image Processing, Vol. 13, No. 4, April 2004.