

A Novel Approach for Despeckling of Sonar Image

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Abstract

Speckle noise in the sonar images causes incorrect interpretation and analysis. It is necessary to extract all essential information from the affected image. From the literature studies carried out, it is found that there are various techniques available for the removal of speckle noise in sonar images. In this paper, the removal of speckle noise in sonar images using spatial filters such as Lee, Frost, Median, Wiener, Mean, Speckle Reducing Anisotropic Diffusion (SRAD) and in frequency domain using Discrete Wavelet Transform (DWT)-Haar along with median, and SRAD has been done. A hybrid technique has been introduced in spatial domain and then a comparative study has been done for all the filters. The performance has been analyzed with the help of quality metrics such as Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR), Visual Information Fidelity Criteria (VIF), Structural Similarity Index Metrics (SSIM) and Correlation. The result concluded that the hybrid of SRAD and Gaussian Filter in spatial domain proves best for the filtering of speckle noise in sonar images among all filters tested here.

Keywords: Despeckling, Hybrid Technique, Sonar Image, Speckle Noise, Quality Metrics

1. Introduction

Sound Navigation and Ranging (SONAR) is used to navigate and detect the underwater objects of the sea. There are two types of sonar namely active sonar and passive sonar. Active sonar is used for various submarine applications like seabed imaging, fish localization, identification of objects under the sea etc., Passive sonar does not emit sound signal by its own, but can be used to detect the emitted sound by other marine objects inside the sea¹. In recent trends, the two active sonar namely the Side Scan Sonar (SSS) and the Synthetic Aperture Sonar (SAS) are used to analyze anomaly detection, characterize seabed texture, find coastal changes, to route pipeline and cable surveys, fish finding and for target detection and classification etc. SSS images are conventionally used in this applications than SAS images because of its cost effectiveness^{2,3}. Hence the same type of images has been used for this research work.

Side scan sonar constitutes of sensors which are emitting sound and recollecting sound in terms of echoes. Images formed using the echoes consist of surplus speckle noise which is formed during the process of image acquisition

and transmission. The speckle noise is modeled as a multiplicative noise and given as equation (1).

$$Y_{ij} = X_{ij} \times N_{ij} \quad (1)$$

Where X_{ij} is the input image, Y_{ij} is the noisy image and N_{ij} is the speckle noise.

The speckle noise degrades the quality of the active sonar images⁴. There are two ways of eliminating speckle noise either by pre-acquisition method or post-acquisition method. The first method needs hardware modification and increases system complexity. But the post-acquisition method uses various filtering techniques which reduces system complexity in handling speckle noise and improves image quality. Many advanced spatial and frequency domain filtering techniques are in progress to obtain a content despeckled sonar image⁵. In this paper, some of the prominent spatial filters namely Lee, Frost, Median, Wiener, Mean, Speckle Reducing Anisotropic Diffusion (SRAD) and filters like median and SRAD, which is defined in spatial domain transferred to the frequency domain by DWT (Haar) and the filters applied directly in frequency domain⁶. The study was also carried out by the combination of SRAD with Gaussian and

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FROST with Gaussian in spatial domain⁷. The above mentioned filters are evaluated for a set of sonar images whose intensity values are ranges from 10% to 100%. The performance efficiency of each filter is evaluated by quality metrics such as Peak Signal to Noise Ratio (PSNR), Mean Square Error (MSE), Visual Information Fidelity Criteria (VIF), Structural Similarity Index Metrics (SSIM), and Correlation^{8,9}.

Section I deals with the overview of spatial domain filters and the frequency domain filters are in section II. In section III proposed hybrid algorithms are explained. Section IV depicts the quality metrics used and its formulae are given. Discussion and the analysis of those techniques are given in section V.

2. Spatial Domain Filters - Overview

In Spatial domain, the filtering technique is applied directly to the image pixels. It is a simple technique and is very useful for preserving pixel information. The spatial domain filtering is done with the help of kernel sub images. The advantage and disadvantages of each spatial filter have been summarized below.

2.1 Mean Filter

A kernel of size 3 X 3 is considered and the centre pixel value of each kernel is replaced by the mean value of the pixels inside the kernel itself. This filter not removing the speckle noise fully but it smoothen the data to some extent.

2.2 Median Filter

This filter comparatively removes the noise better than mean filter. A kernel of size 3 X 3 is selected and centre pixel value of the kernel is replaced with the median of the kernel pixel values. The median is calculated by picking up middle value from the list of pixel values arranged in an either ascending or descending order. It preserves the edge information, however if noise intensity increases the object edges become blur¹⁰.

2.3 Wiener Filter

It restores image in the presence of blur and noise. It performs smoothing of image and preserves high frequency component of the image. But it requires more compu-

tation and works on statistical approach such as auto correlation and cross correlation for a given image.

2.4 Lee Filter

In Lee filter, smoothing of images are done using the weighted equation derived from the Minimum Mean Square Error (MMSE) given by the equation (2).

$$W(x, y) = 1 - \left[c_n^2 / (c_i^2 + c_n^2) \right] \quad (2)$$

Where c_n is the co-efficient of variance of noise and c_i is the co-efficient of variance of noisy image. If the co-efficient of variance increases the smoothing decreases and vice-versa. The filtered de-noised image can be obtained by multiplying the weighted co-efficient with the noisy image. It reduced a speckle noise and preserves the edge information.

2.5 Frost Filter

Similar to Lee filter, frost filter is also derived from MMSE equation. But it is an adaptive filter. The kernel size of the filter varies according to the local statistics method used in it. The weighted function of the filter is given in equation (3)

$$W(x, y) = \sum_{n \times n} k \alpha e^{-\alpha |t|}, \alpha = (4/n\sigma_1^2) (\sigma^2/I_1^2) \quad (3)$$

Where k is normalization constant, I_1 and σ_1 are local mean and variance, σ is the original image variance, $|t| = |x - x_0| + |y - y_0|$, n is kernel size. Finally the weighted function is manipulated with the noisy image and gives the filtered image. It reduces the speckle noise with improved PSNR and preserve edge details than the Lee filter.

2.6 SRAD Diffusion Filter

The filter preserves edge information and suppresses speckle noise effectively. The filter equation is a partial differentiation of noisy image with respect to time. The computation time is always high compared to other filters. Among these filters SRAD is the best solution for removing speckle noise¹¹⁻¹³.

2.7 Gaussian Filter

It smoothes an image by calculating weighted averages in a filter box. It provides smooth gray scale and reduces Bokeh effect in the remote sensing images. As a new

approach, this filter has been used along with SRAD and FROST for reducing speckle noise in SSS.

3. Frequency Domain Filters - Overview

In frequency domain technique, the original image in spatial domain is transformed into frequency domain coefficients and the coefficients are manipulated and then the resultant coefficients are again transformed into the original domain. Many multiscale methods are available for speckle reduction but wavelet is most popular time frequency transfer function. The decomposition diagram using wavelet has been shown in Figure 1 as below.

If the level of decomposition increases, frequency resolution will also increase. Since Haar wavelet transform has a square shaped transfer function, Discrete Wavelet Transform (DWT) can be implemented with this. The decomposition coefficients of wavelet transform are obtained by the following steps.

1. Decompose the noisy image into wavelet coefficients (LL, LH, HL, HH).
2. Compute the wavelet coefficients using thresholding technique or filtering technique for denoising.
3. Apply inverse transform to retrieve the denoised image.

In this process, the fixing of threshold value is a challenging task. The wrong threshold selection will leads to incorrect analysis. Another drawback is due to the independence of the wavelet coefficients would ignore the important dependency information also fails to protect edge information. But in proposed method computation of the wavelet coefficient is done using filtering technique. Since Median filter is a simple filter and SRAD gave good

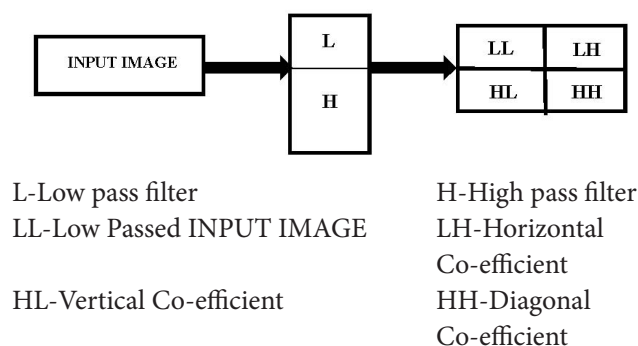


Figure 1. Frequency domain technique.

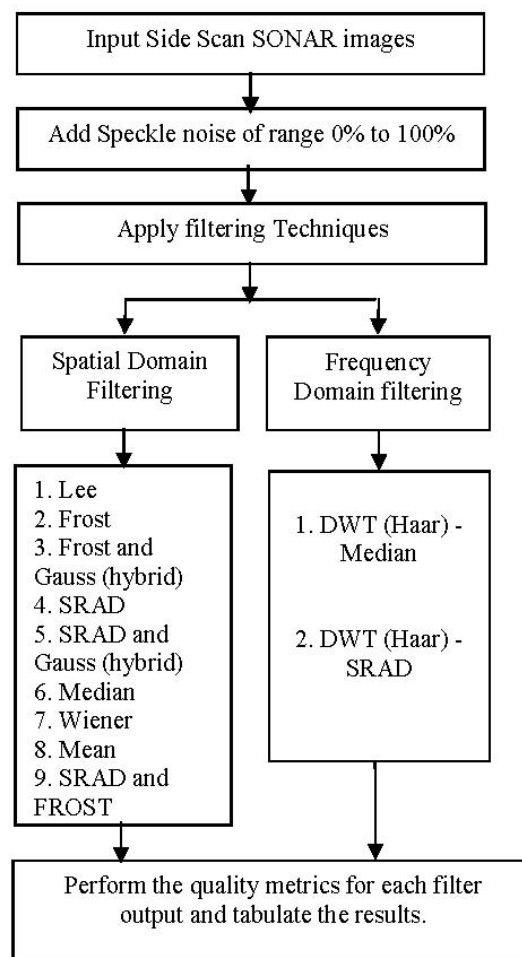


Figure 2. Flow chart of proposed methodology.

performance in spatial domain so both are applied and tested in this domain. The main aim of the speckle filtering is to reduce the noise level, enhance the image quality without affecting the features of the image.

4. Proposed Methodology

A database consist of different sidescan sonar images have been created and the filters are designed and tested. For this work, 50 different side scan sonar images are taken for analysis. Flow chart for denoising of side scan sonar image using filtering techniques has given in the Figure 2.

The following steps in the flow chart can be explained as,

1. Select the input side scans sonar (SSS) image from the given list.
2. Add noise to the images of intensity range (10 to 100) % i.e. (0.1 to 1).

3. Apply spatial filtering techniques like Lee, Frost, SRAD, Mean, Median, Wiener and the hybrid techniques such as, SRAD with FROST, SRAD with Gaussian and FROST with Gaussian to the SSS images.
4. Similarly in frequency domain, apply DWT (Haar) to the SSS image.
5. Filter the DWT decomposed image using median and SRAD separately.
6. Reconstruct the filtered DWT image using Haar discrete inverse wavelet transform.
7. Final output image of each filter is evaluated using quality metrics and the results are tabulated.

Generally side scan sonar images are having black and white image pixels. The speckle noise affects brighter area of the image very much and also having signal dependent characteristics. Therefore in order to get a smooth gray scale over a black and white area of the sonar image, a Gaussian filter along with SRAD and FROST have been implemented individually. All the selected filters have implemented with the help of MATLAB tool¹³.

4.1 Quality Metrics

Among a list of quality metrics, a few of the metrics based on the application are selected and implemented.

Formulae of metrics such as MSE, PSNR, VIF, SSIM, correlation used for the performance evaluation of speckle reduced (denoised) images are listed in the Table 1.

5. Results and Discussions

The analysis based on the proposed methodology using various filtering techniques and the results are listed in the Table 2 and Table 3. Each filter was giving different performance for various noise intensities. In frequency domain the tested filters have poor performance, therefore the statistical average $\frac{\sum x}{[n]}$ of individual performance of only the spatial filters have been done and were shown in Table 4. The results show that, all the filters performance decreases with increase in percentage of noise level. From Table 2, by seeing the average performance of the FROST filter the PSNR, SSIM and correlation values are greater than Lee, Mean, Median and Wiener. So its overall performance is better than those filters. By considering SRAD and FROST, SRAD gave good result for the noise intensity of up to 60% then it got reduced than FROST. Therefore by knowing the percentage of noise in the images, it is easy to select the suitable filter.

Usually VIF lies in the interval [0, 1]; if the input image gets enhanced more than a reference image then

Table 1. Formula for Quality metrics

SI. NO	Type	Performance Metrics	Formula
1	Pixel based metrics	mean square Error(MSE)	$\sum [i_1(m,n) - i_2(m,n)]^2 / m \times n$
		peak signal to Noise ratio(PSNR)	$(10 \log_{10} 255^2) / \text{MSE}$
2	Information fidelity metrics	visual information fidelity criteria(VIF)	filtered output image information/reference image information
3	Human visual system based metrics	structural similarity Index metrics(SSIM)	$\frac{[(2\mu_x \mu_y + c_1)(2\sigma_{xy} + c_2)]}{[(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)]}$ $\mu_x, \mu_y \text{ are estimated mean intensities}$ $\sigma_x, \sigma_y \text{ are standard deviations}$ $\sigma_{xy} \text{ is covariance}$ $c_1 = (k_1 d)^2$ $c_2 = (k_2 d)^2$ $k_1, k_2 < 1$ $d = \text{dynamic range of the images.}$ $\text{default: } d = 255$
4	Correlation metrics	correlation	$\frac{[\sum x_i y_i - (\sum x_i / n)(\sum y_i / n)]}{\sqrt{[(\sum x_i^2 - (\sum x_i)^2 / n)(\sum y_i^2 - (\sum y_i)^2 / n)]}}$

Table 2. Spatial domain filters output

SI No. Filters/Noise level			0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
1	LEE Filter	MSE	476.83	495.72	517.91	537.61	556.5	571.53	578.36	588.44	604.94	616.48
		PSNR	21.35	21.18	20.99	20.83	20.68	20.56	20.51	20.43	20.31	20.23
		VIF	0.21	0.17	0.16	0.14	0.13	0.12	0.12	0.11	0.11	0.11
		SSIM	0.5616	0.556	0.5513	0.5443	0.5413	0.5365	0.5334	0.5317	0.5261	0.5211
		Correlation	0.831	0.8249	0.8144	0.8062	0.7976	0.7884	0.7839	0.779	0.7711	0.7637
2	FROST Filter	MSE	260.01	274.53	294.59	310.23	333.18	355.18	363.26	382.78	400.45	416.94
		PSNR	23.98	23.74	23.44	23.21	22.9	22.63	22.53	22.3	22.11	21.93
		VIF	0.42	0.38	0.32	0.27	0.24	0.21	0.2	0.18	0.17	0.17
		SSIM	0.6472	0.6574	0.661	0.66	0.6578	0.6419	0.6419	0.6324	0.6262	0.6197
		Correlation	0.922	0.9185	0.9091	0.9028	0.8922	0.8748	0.8748	0.8654	0.8575	0.8486
3	SRAD Filter	MSE	147.21	173.08	204.71	242.11	286.45	318.75	342.33	378.7	405.41	432.17
		PSNR	26.45	25.75	25.02	24.29	23.56	23.1	22.79	22.35	22.05	21.77
		VIF	0.41	0.32	0.26	0.22	0.2	0.18	0.17	0.16	0.16	0.15
		SSIM	0.6966	0.6863	0.6763	0.6653	0.6568	0.6463	0.6391	0.6303	0.6253	0.6192
		Correlation	0.9506	0.9409	0.9279	0.9131	0.8955	0.8836	0.8761	0.8635	0.854	0.8467
4	SRAD and Gaussian Filter	MSE	161.84	182.3	207.78	234.18	268.28	294.85	312.86	340.63	360.91	385.86
		PSNR	26.04	25.52	24.95	22.44	23.84	23.43	23.18	22.81	22.56	22.27
		VIF	0.41	0.32	0.27	0.23	0.21	0.19	0.18	0.17	0.17	0.16
		SSIM	0.689	0.6792	0.6707	0.6617	0.6552	0.6466	0.64	0.6334	0.6293	0.6236
		Correlation	0.9468	0.9395	0.9288	0.9184	0.9045	0.8943	0.8881	0.8782	0.871	0.8632
5	Median Filter	MSE	3255.8	3256.38	3256.78	3256.91	3257.4	3257.64	3257.6	3257.88	3258.17	3258.3
		PSNR	13	13	13	13	13	13	13	13	13	13
		VIF	96.84	73.5	58.3	51.51	46.48	42.31	39.5	34.32	34.64	33.21
		SSIM	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578
		Correlation	0.9381	0.9035	0.8636	0.8364	0.8032	0.7746	0.7565	0.7286	0.7115	0.6895
6	Wiener Filter	MSE	3255.04	3255.55	3255.86	3256.14	3256.41	3256.43	3256.26	3256.3	3256.44	3256.26
		PSNR	13.01	13	13	13	13	13	13	13	13	13
		VIF	82.82	71.25	65.12	59.83	57.32	54.23	53.19	51.89	51.79	51.29
		SSIM	0.058	0.058	0.058	0.058	0.058	0.0581	0.0581	0.0582	0.0582	0.0582
		Correlation	0.9419	0.9087	0.8715	0.8421	0.8137	0.7925	0.781	0.7633	0.7488	0.7401
7	Mean Filter	MSE	3255.88	3255.3	3255.59	3255.86	3256.13	3256.09	3255.93	3255.99	3256.09	3255.9
		PSNR	13	13	13	13	13	13	13	13	13	13
		VIF	132.09	107.95	94.42	85.7	79.97	74.68	71.64	68.03	69.06	68.11
		SSIM	0.058	0.058	0.058	0.058	0.058	0.058	0.0581	0.0581	0.0582	0.0582
		Correlation	0.9366	0.9209	0.9001	0.885	0.8665	0.8508	0.8409	0.8293	0.8197	0.8108
8	FROST and Gaussian Filter	MSE	413.99	461.86	476.48	511.28	554.1	567.79	596.96	604.96	642.1	662.58
		PSNR	21.96	21.49	21.35	21.04	20.69	20.59	20.37	20.31	20.05	19.92
		VIF	0.38	0.34	0.3	0.26	0.24	0.23	0.21	0.2	0.19	0.17
		SSIM	0.6319	0.6409	0.6416	0.6441	0.6385	0.6372	0.6325	0.6304	0.6198	0.6163
		Correlation	0.9316	0.9263	0.9251	0.9203	0.9109	0.9072	0.9017	0.8968	0.8894	0.8838
9	SRAD and FROST Filter	MSE	349.92	364.75	381.16	382.65	400.7	400.93	418.37	434.02	447.69	470.12
		PSNR	22.69	22.51	22.32	22.3	22.1	22.1	21.92	21.76	21.62	21.41
		VIF	0.31	0.28	0.26	0.24	0.23	0.23	0.22	0.21	0.2	0.19
		SSIM	0.5796	0.5826	0.5819	0.5821	0.5809	0.5808	0.5806	0.5773	0.5784	0.575
		Correlation	0.8859	0.8797	0.8739	0.873	0.8627	0.8637	0.8539	0.8483	0.8429	0.8346

Table 3. Frequency domain filters output

SI.No	Filters/Noise level		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
1	DWT and Median Filter	MSE	3254.82	3255.3	3255.59	3255.86	3256.13	3256.09	3255.93	3255.99	3256.09	3255.9
		PSNR	13.01	13	13	13	13	13	13	13	13	13
		VIF	97.4	77.75	66.37	59.73	53.78	51.62	49.33	45.36	46.28	46.02
		SSIM	0.058	0.0579	0.058	0.058	0.058	0.058	0.0581	0.0581	0.0581	0.0582
		Correlation	0.9309	0.8957	0.8576	0.8248	0.7933	0.7707	0.7576	0.7352	0.7177	0.7107
2	DWT and SRAD Filter	MSE	3254.85	3255.35	3255.67	3255.94	3256.23	3256.2	3256.03	3256.1	3256.21	3256.02
		PSNR	13.01	13	13	13	13	13	13	13	13	13
		VIF	106.5	83.93	72.14	64.45	58.47	55.17	52.57	48.81	49.38	49.3
		SSIM	0.0578	0.0578	0.0578	0.0578	0.0578	0.0579	0.0579	0.0579	0.058	0.058
		Correlation	0.2789	0.2716	0.2709	0.2681	0.2534	0.2575	0.2506	0.2438	0.2394	0.2395

Table 4. Statistical average performance of spatial domain filters

Parameters/ Filters	Mse	Psnr	Vif	Ssim	Correlation
LEE	554.43	20.7	0.14	0.54	0.80
FROST	339.12	22.88	0.26	0.64	0.89
SRAD	293.09	23.71	0.22	0.65	0.90
SRAD and Gaussian	274.95	23.70	0.23	0.65	0.90
Median	3257.29	13.00	51.06	0.06	0.80
Wiener	3256.07	13	59.87	0.06	0.82
Mean	3255.88	13.00	85.17	0.06	0.87
FROST and Gaussian	549.21	20.78	0.25	0.63	0.91
SRAD and FROST	405.03	22.07	0.24	0.58	0.86

the VIF value will be greater than 1. The filters such as Mean, Median and Wiener filters are selected due to its simplicity, easy to implement and also preserves edge information. The VIF factor is very high for those filters which are used for object identification but all other metrics are less for all noise intensities.

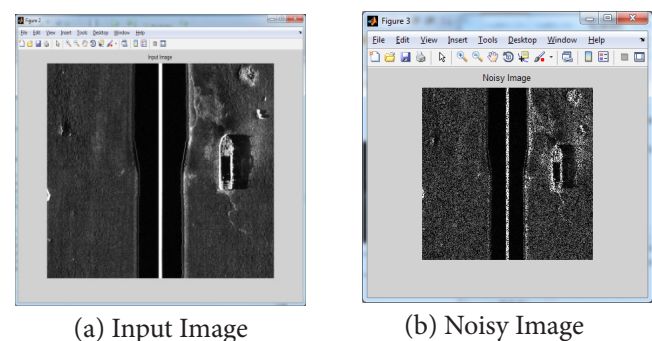
While it is common experience that the enhancement improves quality to a certain extent only and further enhancement will be destroying the quality of the image by the effect of artifacts. It was proved by the filters in frequency domain. Similarly the excessive noise reduction technique will leads to a loss of details and include artifacts. Therefore the combination of both SRAD and FROST has not fit for denoising of side scan sonar images. Even SRAD proved best in spatial domain the effect of median and SRAD have reduced response in the frequency domain.

The Gaussian filter has been selected here for image smoothening. The hybrid techniques like the combina-

tion of SRAD and gauss also the combination of FROST and gauss are performed in spatial domain and the results are listed out in the Table 4. The combination of FROST and gauss filters is having the high performance metrics of correlation and VIF. Similarly SRAD and gauss is having high PSNR and SSIM values. Finally according to the subjective and quantitative analysis, SRAD and gauss filter combination is proved to be best of all filters discussed here. Resultant output images of all the tested filters are given here only for 50% i.e. (0.5) of noise intensity. In Figure 3, the input image and 50% speckle noise added to the same input image are given. Figure 4 and Figure 5 are the output images of different spatial and frequency domain filtering techniques.

6. Conclusion

Speckle noise has been removed by many techniques. This work deals with the denoising of side scan sonar image using some of the standard spatial filters and frequency domain filters. Detailed studies of all those filters and its

**Figure 3.** Input and Noisy (50% of noise intensity) images.

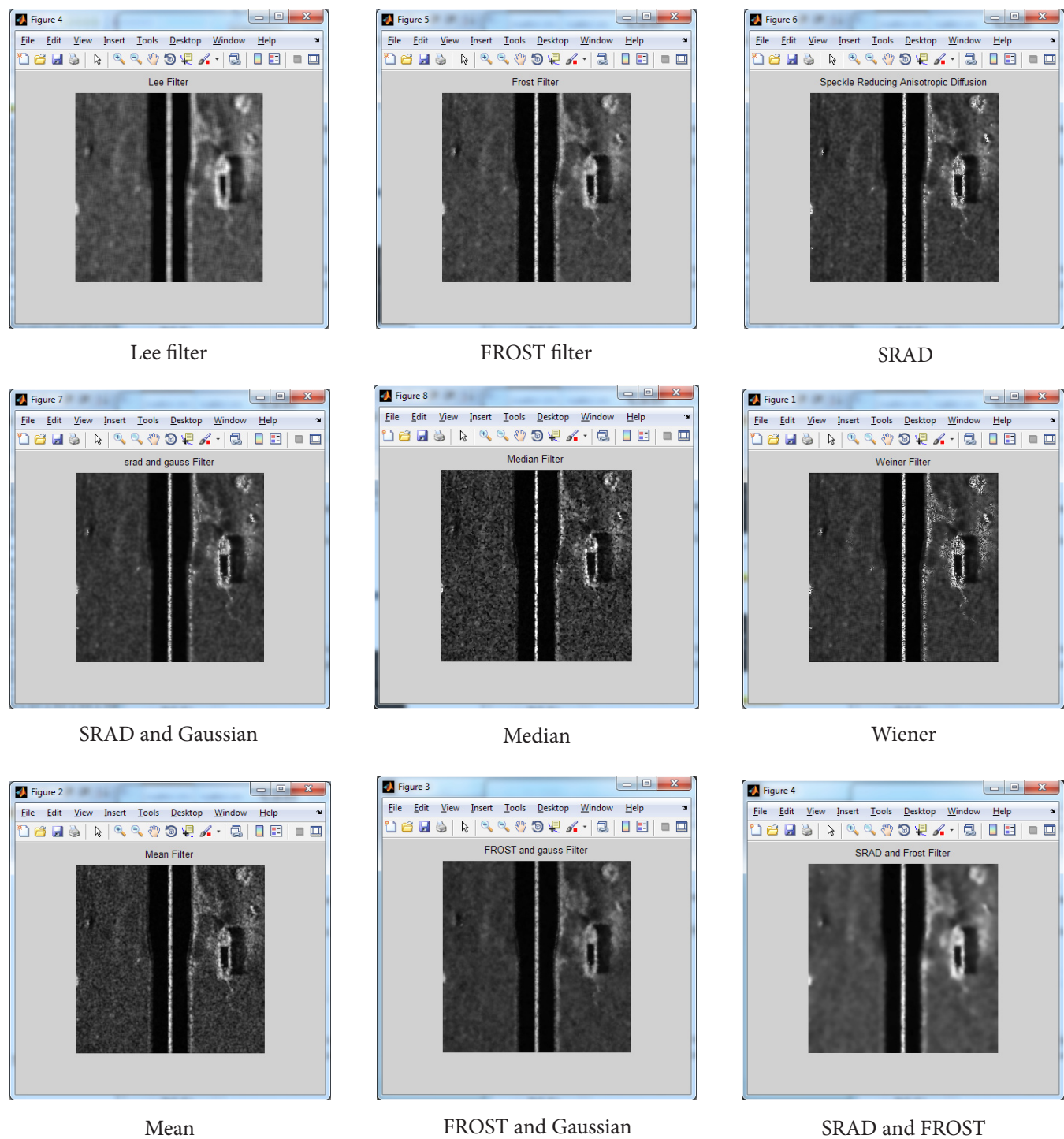


Figure 4. Spatial domain filtering techniques.

quality metrics have been discussed. The hybrid of some standard filters has been proposed in this methodology. In order to illustrate the effectiveness of the proposed methodology we presented our simulation results for

all the noise levels ranges from 10–100% and compared those results with the help of statistical averaging. The comparisons suggest that the combination of SRAD and gauss gives as the better result for extremely speckle

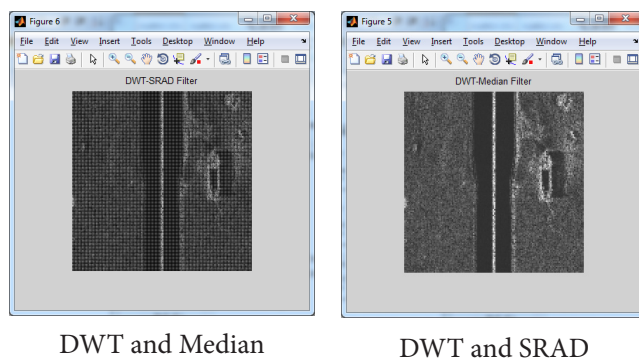


Figure 5. Frequency domain filtering techniques.

noised sonar images. In future we planned to develop an algorithm to estimate the amount of noise present in the sonar image.

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8. References

1. Perona P, Malik J. Scale space and edge detection using anisotropic diffusion. *Proceedings of IEEE Computer Society Workshop on Computer Vision*. Washington: IEEE Computer Society Press; 1987. p. 16–22.
2. Isar A, Moga S, Isar D. A New Denoising System for SONAR Images. *EURASIP Journal on Image and Video Processing*. 2009. Doi:10.1155/2009/173841
3. Atlas N, Gupt S. Reduction of speckle noise in ultrasound images using various filtering techniques and discrete wavelet transform: Comparative Analysis. *IJR*; 2014; 3(5):68–71.
4. Somers ML, Stubbs AR. Sidescan sonar. *IEEE Proceedings of Communications, Radar and Signal Processing*. 1984; 131(3):243–56.
5. Lu H, Yamawaki A, Serikawa S. Curvelet approach for deep-sea sonar image denoising. *Contrast Enhancement and Fusion. Journal of International Council on Electrical Engineering*. 2013; 3(3):250–6.
6. Chumchob, Chen K, Brito-Loeza C. A new variational model for removal of combined additive and multiplicative noise and a fast algorithm for its numerical approximation. *Int J Comput Math*. 2013; 90(1):140–61.
7. Achim A, Tsakalides P, Bezerrianos A. SAR Image denoising Via Bayesian wavelet shrinkage based on Heavy tailed modelling. *IEEE Transaction on GARS*; 2003. p. 1–32.
8. Padmavathi G, Subashini P, Kumar MM, Thakur SK. Comparison of filters used for underwater image pre-processing. *IJCSNS*. 2010; 10(1):58–65.
9. Sheikh HR, Bovik AC. A Visual information fidelity approach to video quality assessment. *The First International Workshop on Video Processing and Quality Metrics for Consumer Electronics*; 2005. p. 23–5.
10. Yoo B, Park H, Ryu J, Hwang K, Nishimura T. Wavelet decomposition based speckle reduction method for ultrasound images by using speckle reducing anisotropic diffusion. *Proceedings of the World Congress on Engineering and Computer Science*; 2008; San Francisco, USA.
11. Yu Y, Acton ST. Speckle reducing anisotropic diffusion. *IEEE Trans Image Processing*. 2002; 11(11):1260–70.
12. Thakur N, Devi S. A new method for color image quality assessment. *Int J Comput Appl*. 2011; 15(2):10–7.
13. Gonzalez RC, Woods RE, Eddins SL. *Digital image processing using MATLAB*. Prentice Hall; 2004.