Annals of R.S.C.B., ISSN: 1583-6258, Vol. 25, Issue 6, 2021, Pages. 1054-1065
Received 25 April 2021; Accepted 08 May 2021.

Statistical Analysis of Speckle Noise Reduction in C-Band SAR Image Using FFT Based Circular Pass Filter And Circular Cut Filter

Atiya Irfan Shaikh[1], Sayyad Shafiyoddin Badroddin[2]

[1]Department of Electronic Science, Abeda Inamdar College of Arts, Science & Commerce, Pune. Maharashtra, India.

[2]Department of Physics, Milliya Arts, Science & Management Science College, Beed, Maharashtra, India.

shaikhatiya8@gmail.com , syedsb@rediffmail.com

Abstract:

Image Enhancement plays a vital role in image processing applications and is an active field of research. In remote sensing, various imaging modalities, i.e., optical, infrared, and microwave satellite sensors, are used to get information about the earth's surface and objects. In Microwave remote sensing, coherent sources are used for imaging purposes. Due to coherent sources, speckle noise gets added to an image during acquisition. It causes loss of information and blurring, which leads to loss of the information of the objects. For eliminating speckle noise, various despeckling filters are used, and their performance is analyzed based on objective assessment parameters. In this paper, the FFT-based frequency domain Circular Pass Filter and Circular Cut Filtering techniques are applied to remove speckle noise from SLC level-1 SAR data. The methods are applied to C- band SAR Sentinel-1A data. The simulated results were analyzed based on performance evaluation parameters as ENL, standard deviation, and coefficient of variance.

Keywords: SAR, Speckle Noise, FFT, IFFT, Circular Pass Filter, Circular Cut Filter

1. Introduction:

SAR imaging modality uses microwaves to produce images of the object over the earth. It is a vital property present in microwave imaging, which sends high-resolution images [1]. The microwave imaging method is generally used to capture images during day and night. These images can be obtained and used in many applications such as land-based applications, oceanographic applications, and atmospheric sciences applications. Multiplicative, i.e., speckle-noise mostly found in the SAR image. It is produced by interfering echoes of transmitting signals form, generated from heterogeneities of the earth's surface. Speckle noise inclines to reduce the quality and consistency in the Microwave images [1][2][3][4][5]. It is seen that radar returns from strong targets frequently form a cluster of a large number of pixels and produce bright and large clusters from distributed media, due to the speckle effect, is very thin [6][7]. Image processing plays an important role in eliminating speckle noises. It recognized image quality

Annals of R.S.C.B., ISSN: 1583-6258, Vol. 25, Issue 6, 2021, Pages. 1054-1065
Received 25 April 2021; Accepted 08 May 2021.

enhancement and increased the visualization accuracy of SAR images. [1]- [4], [8]. There are various image enhancement techniques used to reduce speckle noise and recover the original image effectively. [9] [10] [11], [15-16], In this paper, to reduce speckle noise, frequency domain filters, i.e., Circular Pass Filter, Circular Cut Filter, are applied to Sentinel-1A SLC data to enhance or recover the original image in an effective way. Image quality assessment(IQA) is performed to estimate speckle-noise reduction efficiency. Simulated results quantitatively compare the estimated speckle-noise elimination based on ENL, Mean, Standard Deviation, and Coefficient of variance. Sentinel-1 operates in C-band (5.6 cm) wavelength and provides single or dual-polarization Capability. Here, the VV and VH Dual-Polarization data acquired in Interferometric Wide (IW)
Swath mode is used. Single-Look Complex (SLC) products are images in the slant range, georeferenced using orbit and attitude data from the satellite. SLC products are single-look. Hence, they have not been averaged and comprise complete speckle information.

This paper is organized as follows: Section 2 describes the speckle noise model, in section 3, frequency domain filtering techniques are described, performance evaluation of despeckling filters in terms of quantitative and evaluation parameters is given in section 4, while in section 5, performance evaluation parameters of despeckling filters in terms of objective assessment described. Section 6 elaborates the performance measurement based on the quantitative review of various filters and elaborated in section 7.

2. Speckle Noise Mathematical Model In Microwave Images:

Noise is the source of finite exposure time present in the SAR imaging device due to the signal's stochastic and random arrival. It is an unwanted variation in an image's pixel values and causes degradation in image quality [15]-[16]. Due to random or stochastic processes, it is challenging to find noise values, but we can easily determine noise's statistical property. Unwanted noise is always present in the image; different types of noises can be recognized accordingly with their origin. An image generated from the SAR echo returns is represented by spatial variations of pixel intensities over the area.

$$(m, n) = S(m, n) * U(m, n) + V(m, n) \quad \text{---------} \quad (1)$$

Where (m, n) is the noisy pixel, S(m, n) represents the noise-free pixel, U(m, n), and V (m, n) represents the multiplicative and additive noise, respectively, and m,n are indices of the pixel locations. As the effect of additive noise is considerably smaller when compared to that of multiplicative noise. Then speckle noise model may be approximated as multiplicative Noise and is given by.

$$(m, n) = S(m, n) \quad \text{----------------------------} \quad (2)$$

2.1 Frequency Domain Filtering Techniques:

Basically, there are two types of enhancement techniques used for image enhancement: spatial domain techniques and frequency domain techniques classified based on smoothing and sharpening the images [15]. Smoothing of the image can be achieved in the frequency domain by eliminating the high-frequency components using circular pass filters, which pass only low frequencies components and drop the high-frequency components. While circular-cut filters allow only high pass frequencies above a minimum value. The 2-D Fourier Transform is a powerful tool used to enhance the image quality, restore, encode, and any images. [8]

Annals of R.S.C.B., ISSN: 1583-6258, Vol. 25, Issue 6, 2021, Pages. 1054-1065
Received 25 April 2021; Accepted 08 May 2021.

The FFT algorithm is used in numerous image processing applications to reduce computational costs. The FFT algorithm is easy to implement by using the successive doubling technique. If f(x) is a continuous function of a real variable x. The Fourier Transform F (u) of given function f(x) is defined as:

$F\,(\,) = f\,(x\,)e^{-j2\pi ux}\,dx \qquad where\; j = -1$ ---------------------------------- (3)

Inverse Fourier Transform: $f\,(x) = F\,(u)^{-j2\pi ux}\,du$ ------------------------------------ (4)

The two dimensional Fourier transform is given by

$F(\,u,v) = f(\,x,y\,)e^{-j2\pi(ux+vy)}dxdy$ --(5)

Inverse Fourier Transforms: $f\,(x,\,) = F(\,u,v)\; e^{j2\pi(ux+vy)}dudv$ ----------------------------(6)

Initially, a Forward Fourier Transform is applied to the image. It converts image data into a complex output image and gives its various spatial frequency components. The transformed image is then multiplied with the filter function image. It interactively builds a frequency filter. The filtered image is then Inverse Fourier transformed into the spatial domain, and inverse FFT transforms the filtered data to the original data space. Removing high frequencies components results in a smoother image in the spatial domain, and low filtering frequencies enhance the image's edges. Frequency domain filtering is based on the Fourier Transformation. In the method, the image and a filter function are multiplied pixel-by-pixel.

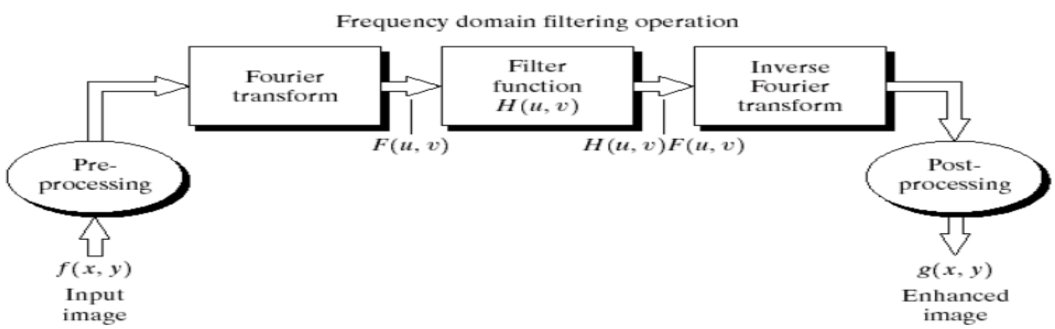


Figure1. Frequency Domain Filtering Operation

The basic model for FFT based frequency domain filtering is given by :

G (u ,v) = H(u, v)F(u, v) ---------- (1)

F (u, v) is the Fourier transform of the input image to be filtered. It shows both the horizontal and vertical spatial frequency components of an image. The average brightness value of the image (zero frequency component) is shown in the transformed image center. Pixels away from the center represent increasing spatial frequency components of the image.

H(u,v) is the filter transform function. It is a single band image of the specified dimensions

Annals of R.S.C.B., ISSN: 1583-6258, Vol. 25, Issue 6, 2021, Pages. 1054-1065
Received 25 April 2021; Accepted 08 May 2021.

Inverse Fourier Transform image, i.e., Filtered image f(x, y), is given by

$$F(x, y) = \Im^{-1}\{F(u, v)\} \quad \text{------(7)}$$

As H(u,v) is the filter transfer function DFT of the filter impulse response, The execution is performed by multiplying the filter H(u,v) point-wise with the function F(u,v). Real filters are called zero phase shift filters because they don't change F's phase (u,v). Then, the filtered image was obtained by taking the inverse DFT of the resulting image.

$$\text{Filter Image} = \Im^{-1}[G(u,v)] \quad \text{------(8)}$$

The filtered image consists of imaginary components even if the original image f(x,y) and the filter h(x,y) are real. These are due to numerical errors and are neglected. The final result is thus the real part of the filtered image.

A: Circular Pass Filter

A Circular Pass Filter is a filter that passes low-frequency signals and attenuates signals with higher frequencies than the cut-off frequency. The actual amount of attenuation for each frequency varies depending on the specific filter design. Smoothing is primarily a lowpass operation in the frequency domain. Ideal Circular Pass Filters is the simplest lowpass that cuts off all high-frequency components of the Fourier Transform that are at a distance greater than a specified distance D from the origin of the Transform. The transfer function of an ideal Circular Pass filter is given by:

$$H(u,v) = \begin{cases} 1 & \text{if } D(u,v) \le D_0 \\ 0 & \text{if } D(u,v) > D_0 \end{cases} \quad \text{------(9)}$$

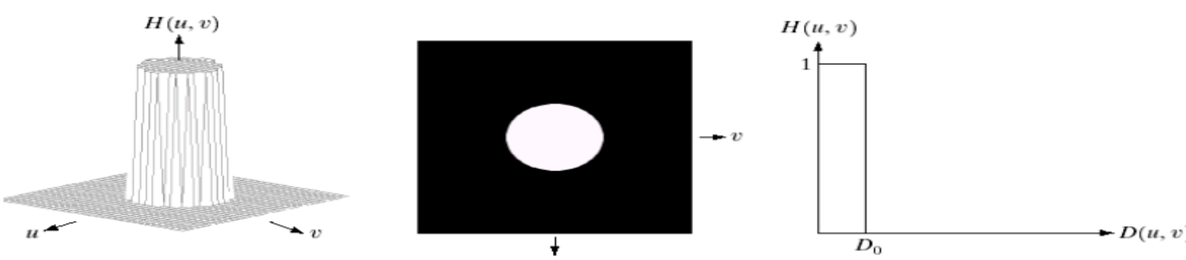


Figure 2: Ideal Response of the Circular Pass Filter

$$D(u,v) = [(u - M/2)^2 + (v - N/2)^2]^{1/2} \quad \text{------(10)}$$

Where D(u,v) is the distance from the point (u,v) to the center of their frequency. And (M/2, N/2) is the center point. The figure shows an ideal response of the Circular Pass Filter. The white areas will be filtered out of the image

Annals of R.S.C.B., ISSN: 1583-6258, Vol. 25, Issue 6, 2021, Pages. 1054-1065
Received 25 April 2021; Accepted 08 May 2021.

B: Circular Cut Filter

A Circular Cut Filter is a filter that passes high frequencies but attenuates frequencies lower than the defined cut-off frequency. Sharpening is fundamentally a highpass operation in the frequency domain. The Circular Cut Filter (H_{HP}) is represented by its relationship to the lowpass filter (H_{LP}) as

$$H_{\text{HP}} = 1 - H_{\text{LP}} \quad \text{-------------------------------------} \quad (11)$$

The ideal high pass filter is given as:

$$H(u,v) = \begin{cases} 0 \text{ if } D(u,v) \leq D_0 \\ 1 \text{ if } D(u,v) > D_0 \end{cases} \text{-------------------------------------}(12)$$

D0 is the cut-off distance; the figure shows an ideal response of the Ideal Circular Cut filter. The white areas will be filtered out from the image

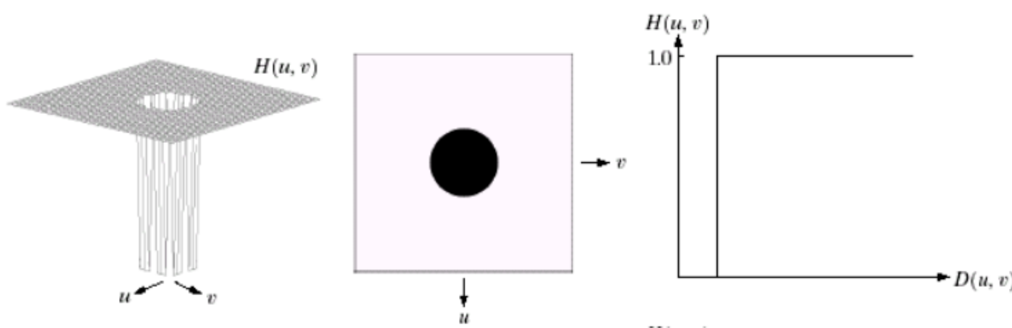


Figure 3: Ideal Response of the Circular Pass Filter

3. Methodology:

3.1. Methodology:

1. Input Sentinal-1 SLC Level-1 image
2. Apply Georeferencing to the input image.
3. Define an FFT filter to remove particular frequency components.
   a. Enter values of the Samples and Lines
   b. Select Filter Type with different cut-off frequencies (radius).
   c. Enter the Number of Border Pixels to taper the filter.
4. Apply Forward Fourier Transform to produce complex image data.
5. Get Fourier transformed image by Multiplying the FFT filter to the forward FFT of the input image.
6. Apply Inverse Fast Fourier Transform(IFFT) to the FFT transform image.
7. Compare ENL, Mean, Median, Standard Deviation, and Coefficient of variance.

4. Study Area:

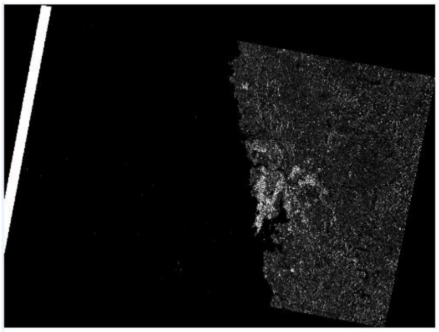


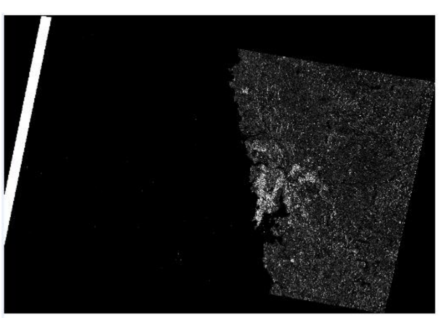
Figure-4: Study Area

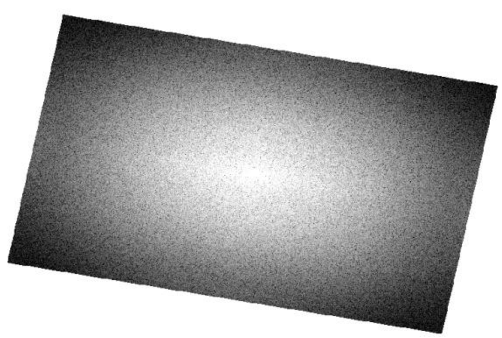
In this work, dual-polarized C- Band Sentinel-1A, SLC having IW beam mode data acquired on 15-05-2019 is used. The study area is well Known city, Mumbai, Maharashtra, India. It covers the geographical area from Lattitude 19.849155°N Longitude 73.918283°E, Lattitude: 20.283514°N Longitude 71.491980°E, Lattitude 18.776391°N Longitude:71.200208°E, Lattitude 18.338632°N Longitude 73.603190°E. Data has 25806.000 Columns and 16743.000 Rows. [16]

5. Result and Discussion:

The experimental work carried out using Envi 5.3 software. Envi software supports many features and capabilities for the analysis of the SAR data. The speckle noise reduction value was considered as the performance parameter. The Circular To reduce speckle noise from the image FFT based Circular pass and Circular cut filters with different cut-off frequencies applied to the C-Band sentinel-1 data. Elimination of speckle-noise from an image is studied by comparing statistical parameters such as ENL, Standard Deviation, coefficient of variance, Mean, and Median. These are essential parameters to decide the quality of the image. The assessment techniques are used to evaluate the performance of the despeckling algorithms.

An experiment has been conducted to quantitatively evaluate the Frequency domain filtering techniques applied to c-band Sentinel-1 SAR imagery. Processing techniques as Circular Pass Filter and Circular cut Filter were assessed as sources for comparison. The Circular Pass filter retains low-intensity components and removes all high-intensity components from the image. It also provides a Lower standard deviation and the least coefficient of variance for Circular pass filtered images with higher cut-off frequency. The circular cut FFT filter generates a good quality image except for Low contrast edges.

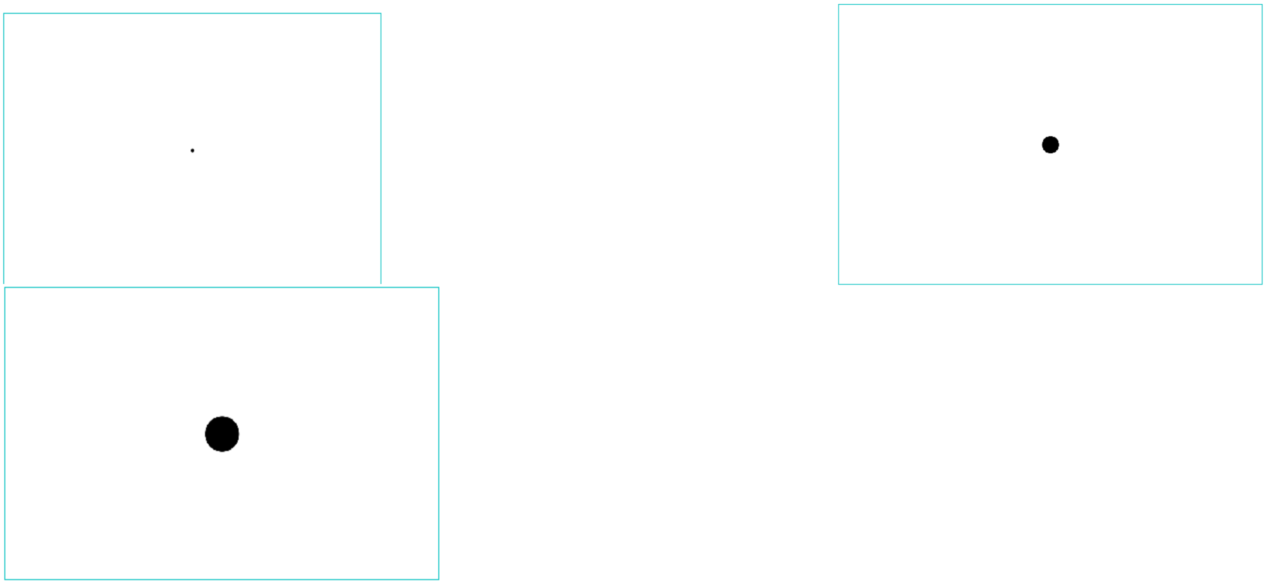




Annals of R.S.C.B., ISSN: 1583-6258, Vol. 25, Issue 6, 2021, Pages. 1054-1065
Received 25 April 2021; Accepted 08 May 2021.

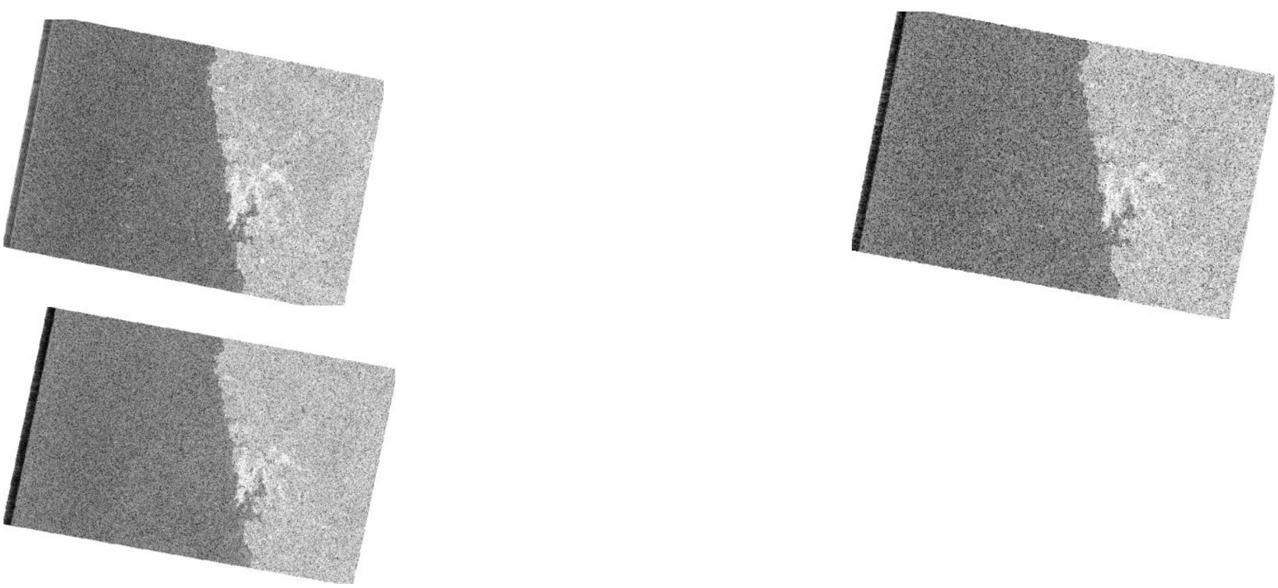
a) b)

Figure 5: a) Sentinel-1A Level-1 SLC VH-Polarized Image b) Forward FFT



a) Radius= 100 b) Radius= 500 c) Radius= 1000

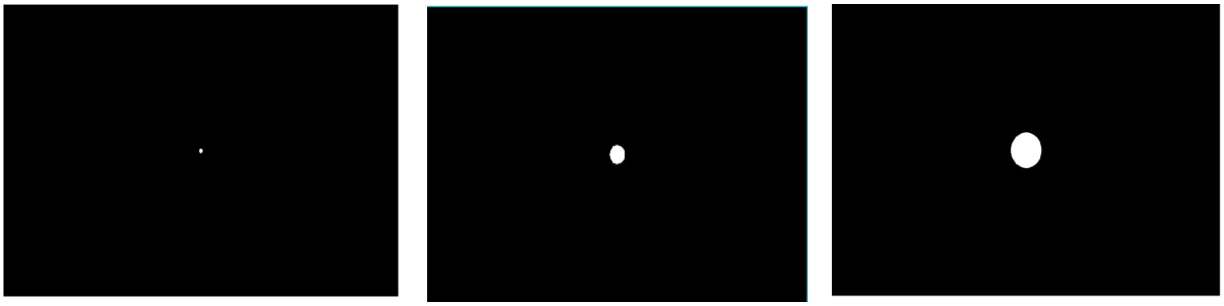
Figure 6: Define Circular Cut FFT Filter



a) **Radius= 100 b) Radius= 500 c) Radius= 1000**

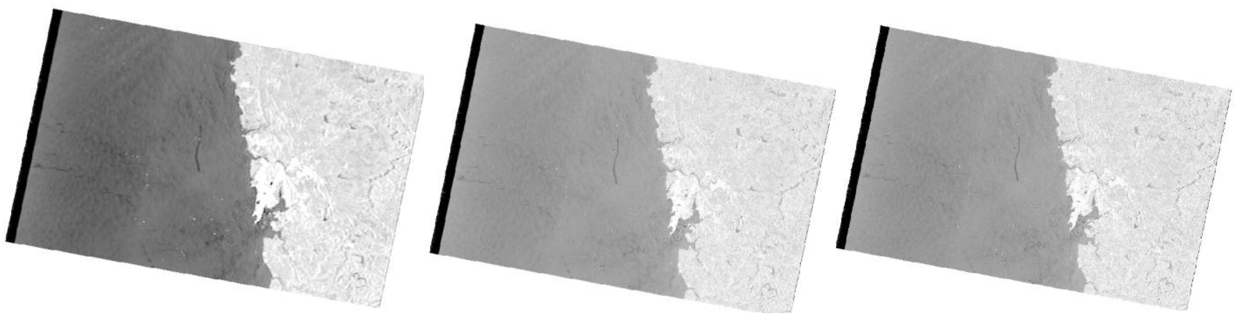
Figure 7: Circular Cut Filtered Images

Annals of R.S.C.B., ISSN: 1583-6258, Vol. 25, Issue 6, 2021, Pages. 1054-1065
Received 25 April 2021; Accepted 08 May 2021.



a) Radius= 100 **b)Radius= 500** **c) Radius= 1000**

Figure 8: Define Circular Pass FFT Filter



a) Radius= 100 **b)Radius= 500** **c) Radius= 1000**

Figure 9: Circular Pass Filtered Images

Table1: Accuracy Estimation of The Circular Cut Filter Inverse FFT Images

Parameters	Circular Cut Filter		
	Radius =100	Radius =500	Radius =1000
Number of pixels total	384305	364305	388345
Minimum	0.0	0.0	0.0
Maximum	255.0	255.0	255.0
Mean:	158.77844160237703	155.3573159852313	161.68609870089617
Standard Deviation	64.91054974584844	61.9237128020314	63.92627775257590 6

Annals of R.S.C.B., ISSN: 1583-6258, Vol. 25, Issue 6, 2021, Pages. 1054-1065
Received 25 April 2021; Accepted 08 May 2021.

Coefficient of Variation:	0.4088121100747514	0.3985889715545681	0.39537275168493 87
Median:	155.3530398736676	155.20818081991217	160.319112931955 83
ENL	2.117	2.2280	2.2840

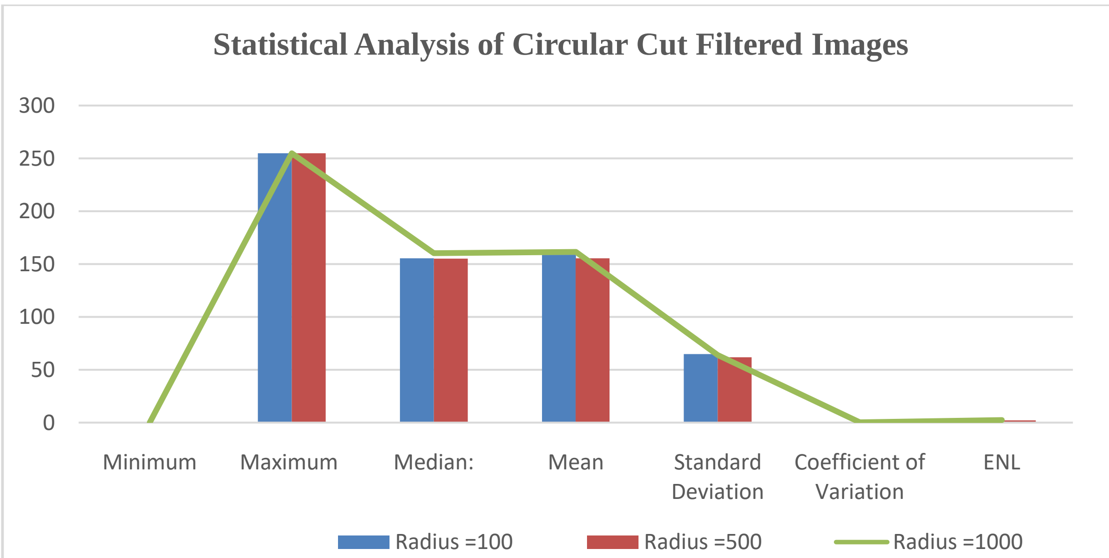


Figure 10. Statistical Analysis of Circular Cut Filtered Images

Table 2: Accuracy Estimation of The **Circular Pass Filter Inverse FFT Images**

Parameters	Circular Pass Filter		
	Radius= 100	Radius =50	Radius =1000
Number of pixels total	364780	381340	379054
Minimum	0.0	0.0	0.0
Maximum	255.0	255.0	255.0
Mean:	190.016988321722 52	192.838928515236 97	208.054451344659 87
Standard Deviation	68.2953036882628	68.0963616623847 5	50.5390542509519 14
Coefficient of Variation:	0.35941683052375 46	0.35312559651047 94	0.24291263140162 128
Median:	224.75	226.75	225.75
ENL	2.9439	3.0985	6.0087

Annals of R.S.C.B., ISSN: 1583-6258, Vol. 25, Issue 6, 2021, Pages. 1054-1065
Received 25 April 2021; Accepted 08 May 2021.

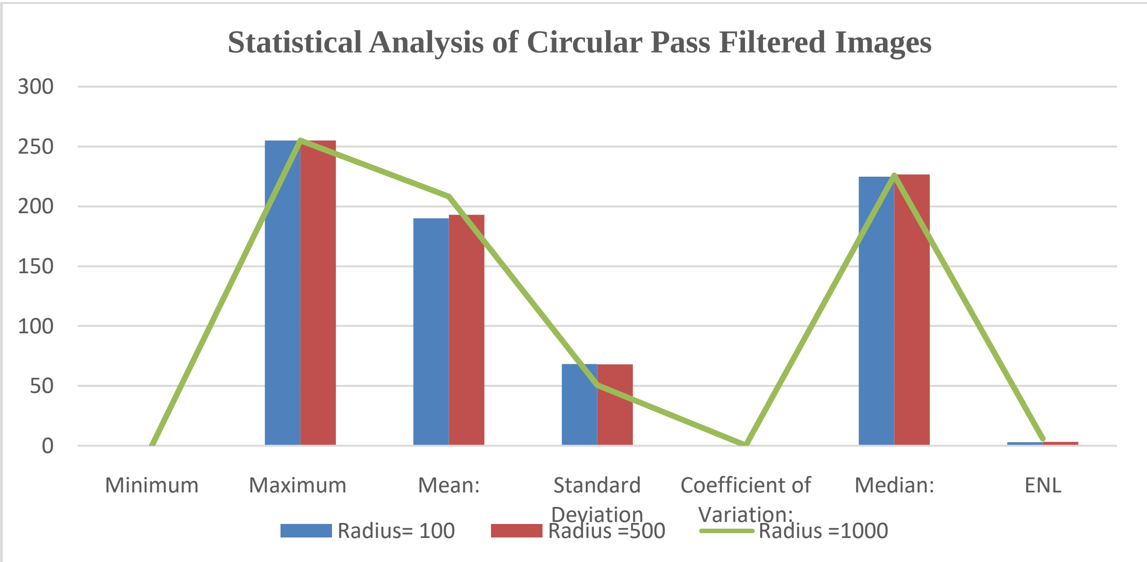


Figure 11.Statistical Analysis of Circular Pass Filtered Images

The experimental work carried out using Envi-5.3 software. Envi software supports many image enhancement features, and it also has capabilities for analysis of the SAR images. In this work, the speckle noise reduction value is considered as the performance parameter. To reduce speckle noise from the image FFT based Circular Pass and Circular Cut filters with different cut-off frequencies are applied to the C-Band Sentinel-1A SLC data. Elimination of speckle-noise from an image is studied by comparing statistical parameters such as ENL, Standard Deviation, Coefficient of Variance, Mean, and Median. These are essential parameters to decide the quality of the image. The assessment techniques are used to evaluate the performance of the despeckling algorithms.

The Study Area is as shown in Figure 4. Figure 5(a) indicates the SLC VH0Polarized Sentinel-1A image, and Figure 5(a) represents the FFT spectrum of the input image. Fig 6. (a-c) represents the Define FFT Circular Cut Filter for an input image. Figure7. (a-c) illustrates the results of Circular Cut filter IFFT images with the change in filter radius showing significantly reduced speckle noise. Table1 and Figure 10 represent the accurate estimation and statistical analysis of the Circular Cut Filter IFFT images with overall accuracy. The experiment was carried out by varying the filter cut-off frequency (Radius) as 100, 500, and 1000. Results show that the Circular Cut filtered image with a bigger radius (1000) FFT filter has a minimum standard deviation (63.93), most negligible Coefficient of Variance (0.395), and larger ENL (2.284). It is also seen that the edges in the image appear very clear.

Fig 8. (a-c) represents the Define FFT Circular Pass filter. Figure 9(a-c) illustrates the useful Circular Pass filter IFFT images with the change in filter radius showing significantly reduced speckle noise.Table.2 and Figure11.represents the accurate estimation and Statistical analysis of the Circular Pass Filter IFFT images. With overall accuracy. It indicates that a Circular Pass Filter with a radius of 1000 has a lower standard deviation (50.5), Coefficient of Variance (0.2429) larger ENL (6.0087). It is observed that the Circular Pass filter retains low-intensity components and removes all high-intensity parts from the image. It also provides a Lower standard deviation and the least coefficient of variance for

Circular Pass filtered images with a higher value radius. The circular Pass filter generates a good quality image by reducing speckle noise, but it reduces the brightness at the image's edges.

Conclusion:

Frequency domain FFT circular Pass and Circular Cut filter are very useful filters and can also reduce speckle noise. The Circular pass filter retains low-intensity components and removes all high-intensity elements from the image. The circular cut FFT filter generates a good quality image except for Low contrast edges. As Sharp edges and feature boundaries contain high-frequency components, it degrades the qualities of the image. The resulting Resolution loss has highly undesirable consequences for image interpretation. The primary goal of speckle filtering should be to reduce the Speckle noise without sacrificing the information content. This can be achieved by changing the radius of the filter. The highest radius of the circular-cut filter gives better results but maintaining the information present in the image.

.

References:

[1] H A N D B O O K Of Image A Nd Video Processing, Al Bovik, Department Of Electrical And Computer Engineering, The University Of Texas, Academic Press, 2000 By Academic Press.

[2] Indian Journal of Radio and Space Physics,vol-19, October & December 1990, pp-343-358

[3] Rajeshwar Dass, Priyanka and Swapna Devi (2011) "Speckle Noise Reduction Techniques " International Journal on Electronic and Electrical Engineering, (IJEEE) 16: 47-57.

[4] Seema Asht and Rajeshwar Dass (2012) "Pattern Recognition Techniques." International Journal of Science, Engineering & Computer Technology (IJSECT) 2(1) : 125-27.

[5] Rajeshwar Dass (2018) "Speckle Noise Reduction of US Images using BFO cascaded with Wiener filter and DWT in Homomorphic Region." Procedia Computer Science Journal Elsevier 132: 1543-1551.

[6] J. Lee et al. (2009) "Improved Sigma Filter for Speckle Filtering of SAR Imagery." IEEE Trans. Geosci. Remote Sens. 47(1): 202–213.

[7] J. S. Lee, "Speckle suppression and analysis for synthetic aperture radar images," Opt. Eng., Vol. 25, no. 5, pp. 636–643, May 1986].

[8] J. S. Lee, P. Dewaele, P. Wambacq, A. Oosterlinck, and I. Jurkevich, "Speckle filtering of synthetic aperture radar images—A review," Remote Sens. Rev., vol. 8, pp. 313–340, 1994.]

[9] Aziz Makandar And Bhagirathi Halalli "Image Enhancement Techniques using High pass And Lowpass Filters" International Journal of Computer Applications (0975 – 8887), Volume 109-No. 14, January 2015.

[10] S. Dewangan and A. Sharma (2017), "Image Smoothening and Sharpening using Frequency Domain Filtering Technique." Int. J. Emerg. Technol. Eng. Res. 4: 169–174.

[11] S. Shaikh (2016). "Analysis of Digital Image Filters in Frequency Domain," Int. J. Comput. 40(6): 12–19

[12] Rajeshwar Dass, Priyanka, and Swapna Devi(2012) "Image Segmentation Techniques." International Journal of Electronics & communication Technology(IJECT) 3(1): 66-70.

[13] Sentinel-1 products, "ESA Technical Guides, A Layman's Interpretation Guide to L-band and C-band Synthetic Aperture Radar data." Version 2.0,15 November 2018, CEOS, Global Forest Observations Initiative

[14] A. K. Boyat and B. K. Joshi (2015). "A Review Paper: Noise Models In Digital Image Processing." Signal Image Process. An Int. J. 6(2): 63–75.

[15] R. M. Howard (2015). "White Noise: A Time-Domain Basis.", Int. Conf. Noise Fluctuations. June 2015.: 1–4.

[16] https://search.asf.alaska.edu