IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Comparative Study of Various Single Product Speckle Filters of SAR Dataset of Sentinel-1 Satellite for Speckle Noise Reduction

[1]*Pornima Jagtap*, [2]*Sayyad Shafiyoddin*
[1]*Research scholar*, [2] *Associate Professor*
Department of Physics
[1]*Milliya Arts, Science and Management Science College, Beed, India*

Abstract: The microwave Synthetic Aperture Radar (SAR) is a type of active remote sensing. Speckle noise in SAR imagery was produced due to different backscatter response from the objects in the earth surface which reducing the capability to identify object from radar imagery. SAR data are affected by speckle noise. This noise complicates the problem of interaction of the image by reducing the exactitude of the information. That is why speckle reduction is necessary before image analysis. Image filtering is important field in SAR image processing. This paper proposes the comparative study of Sentinel-1 GRD datatype to assess the performance of various types of single product speckle filters such as Boxcar, Median, Lee, Gamma map, Frost, Refined lee and IDAN. The results have been presented by various single product speckle filters on the basis of statistical analysis using parameter Viz. Mean, Standard Deviation, Coefficient Variance, ENL and Max. Error.

Keywords: **Synthetic Aperture Radar (SAR), Sentinel-1 GRD datatype, speckle noise, Boxcar, Median, Lee, Gamma map, Frost, Refined lee and IDAN Statistical Parameters, Mean, Standard Deviation, Coefficient Variance, ENL and Max. Error.**

Introduction

The microwave SAR is an active remote sensing system (Jensen, 2014) [1], which acquired very high-resolution images of the Earth. It has its own energy source for illumination. It receives the radiation reflected from the target on the ground surface. It enables observation in all types of weather condition, day and night. It has the capacity to penetrate through clouds, fog, smoke etc. though there is change in environmental changes and capable to sense the object on the Earth [2]. In this paper Microwave Sentinel-1 GRD IW datatype is used. The objective of these works is to reducing Speckle noise SAR image using the various filters & analyzed and compare the filtered image on the basis of statistical parameters. The statistical parameters Viz. Mean, Standard Deviation, Coefficient Variance, ENL and Max. Error. This paper will provide Boxcar, Median, Lee, Gamma map, Frost, Refined lee and IDAN filters information and comparative simulation model result of filters using SNAP software. This software's are freely available on the internet developed by ESA.

Sentinel-1 GRD datatype product

Sentinel data products are made available systematically and free of charge to all data users. The data will be delivered within an hour of reception for Near Real-Time (NRT) emergency response, within three hours for NRT priority areas and within 24 hours for systematically archived data. Data products are distributed in the Sentinel Standard Archive Format for Europe (SAFE) format. Each mode can potentially produce products at SAR Level-0, Level-1 SLC, Level-1 GRD, and Level-2 OCN. Data products are available in single polarisation (VV or HH) for Wave mode and dual polarisation (VV+VH or HH+HV) or single polarisation (HH or VV) for SM, IW and EW modes. In this paper we used Level-1 GRD datatype, dual polarization (VV+VH) for IW. Ground Range Detected (GRD) products consist of focused SAR data that has been detected, multi-looked and projected to ground range using an Earth ellipsoid model. Phase information is lost. The resulting product has approximately square spatial resolution pixels and square pixel spacing with reduced speckle at the cost of worse spatial resolution. The Interferometric Wide (IW) swath mode is the main acquisition mode over land and satisfies the majority of service requirements. It acquires data with a 250 km swath at 5 m by 20 m spatial resolution (single look). IW mode captures three sub-swaths using Terrain Observation with Progressive Scans SAR (TOPSAR) [19].

Sentinel-1 Synthetic Aperture Radar (SAR) multispectral imagery from the European Space Agency (ESA) used in this study were downloads from the Copernicus Sentinel Scientific Data Hub [7]. Sentinel-1 was collected using an interferometric wide swath mode of the VH (vertical transmit-Horizontal receive) and VV (vertical transmit-vertical receive) polarizations. Sentinel- 1 data is acquired on 26th August 2021 which is the closest time to the field data acquisition time. With a pixel size of 10 m, Pixel spacing 10*10 m, number of looks 5*1, ENL 4.4, the SAR images are at a high-resolution (HR) level-1 ground range detected (GRD)datape processing level.

Methodology:

Image data set is required to be applied in the implemented approach. There are many approaches deal with the image analysis such as histogram analysis, feature extraction, image understanding, and statistical approach. Here we used statistical approach. This approach is concentrated on five parameters of statistical measures that are mean, coefficient variant (C.V.), equivalent number of looks (E.N.L.) and maximum error value of image which reflect the speckle noise reduction in an image.

The proposed approach is divided into four main steps:

•The first step (Input images): In this step, images are collected from satellite to capture SENTINEL-1 SAR image. The acquisition of SAR image is raw level image [7].

• The second step (Pre-processing): In this step, process the raw SENTINEL-1 SAR image using SNAP software. Images are resizing and filtering to reduce noise and redundancies as possible. This is an important stage to prepare an image that is ready for the processing stage [11][9][8][6].

• The third step (Statistical measures): In this step, input image band (Amplitude_VH, Intensity_VH and Amplitude_VV, Intensity_VV), various Filters images (Sigma0_VH, Sigma0_VV). The mean, standard deviation values and correlation are calculated of grey and color images. Various filters apply in single product speckle filtering.

• The fourth step (Compare the results): In which compare the input/raw data (Amplitude_VH, Intensity_VH and Amplitude_VV, Intensity_VV) images, various filtered images (Sigma0_VH, Sigma0_VV) are compare and calculate statistical results of mean, median, standard deviation (Sigma), coefficient variation (C.V.), number of looks (E.N.L.) and Maximum Error values. This stage is realizing the difference in values between input, various filtered images [21].

Experimental Analysis:

Speckle Filtering:

Speckle filtering consists of moving a kernel over each pixel in the image, using the pixel values under the kernel and replacing the central pixel with the calculated value by applying a mathematical calculation. The kernel is moved along the image one pixel at a time until the entire image has been covered. The visual appearance of the speckle is reduced by applying the filter a smoothing effect is achieved [10][12].

Polarimetric SAR Data Speckle Filters

Filtering is a technique to remove unwanted signal/noise to get desired signal in an image. Speckle in synthetic aperture radar (SAR) images is due to the coherent interference of waves reflected from many elementary scatterers. This effect causes a pixel-to-pixel variation in intensities and the variation manifests itself as agranular noise pattern in SAR images [7]. Most of the geophysical media, as for the instance: rough surfaces, vegetation ice, snow, etc. have a very complicated structure and composition. Consequently, the knowledge of the exact scattered electromagnetic field, when illuminated by an incident wave, is only possible if the complete description of the scene was available. This type of description of the scatterers is unattainable for practical applications. The alternative is to describe them in a statistical form [9]. To removing noise signal, enhance the edge without changing information and preserve texture and also provide a good visual appearance using speckle filter. Apply a mathematical calculation, the kernel window moves also substitutes the value of the window central pixel. As a result, the smoothing effect and visual appearance reduced speckle is achieved [1]. The main objective of the present work is to provide a comparative study of Pol-SAR speckle noise filters with the intention to find the strengths of the different approaches. The objective is not providing the details information of filtering, but only the filtering principle on which it is based on [4]. Here used some speckle filters:

Box Filter:

It is a simple averaging filter that replaces the center pixel in a square kernel by the mean value of kernel pixels. Box filter has a good performance in reducing speckle in homogeneous area. Because of dealing similarly with all pixels in a kernel it degrades spatial resolution and also destroys the polarimetric properties [4]. Figure2(a), (b), (c) shows intensity image obtained using a boxcar filter. This image shows enhanced contrast and lower random aspect. As it can be seen, the boxcar filter is characterized by two main limitations:

- Sharp edges are generally blurred.
- Point scatterers are over filtered and transformed to spread targets [4].

Median Filter [15]:

It is non-linear filter invented by Pitas in 1990. It gives quite better result than the mean filter. Here center pixel is replaced by the median value of all pixels and hence produces less blurring. Due to this nature, it is used to reduce impulsive speckle noise. Advantage is it preserves the edges. Disadvantage is extra time needed for computation of the median value for sorting N pixels, the temporal complexity is O (N log N). Median filter follows algorithm as follows:

1. Take a 3 × 3 (or 5×5 etc.) region centered around the pixel (i, j).
2. Sort the intensity values of the pixels in the region into ascending order
3. Select the middle value as the new value of pixel (i, j).

Lee Filter:

Lee filtering is a standard deviation-based (sigma) filter that filters data based on statistics calculated within individual filter windows. Unlike a typical low-pass smoothing filter, the Lee filter preserve image sharpness and detail while suppressing noise. The filtered pixel is replaced by a value calculated using the surrounding pixels [5].

Gamma map:

Gamma Map Filter Proposed by Lopes in 1993, uses coefficient variation and contrast variation. It is again better than Frost and Lee filter and also minimizes the loss of texture information. Working of Gamma Map filter is similar to Enhanced Frost filter except that if local coefficient of variation falls between two thresholds, then pixel value is based on the Gamma estimation of the contrast ratios [16].

Frost:

Invented by Frost in1982, is linear, convolutional filter used to remove the multiplicative noise from images. This filter works on the basis of coefficient of variation which is the ratio of local standard deviation to the local mean of the corrupted image. Within the kernel size of n by n then the center pixel value is replaced by weighted sum of values of the neighborhood in kernel. The weighting factor decrease as we go away from interested pixel and increase with variance. It assumes multiplicative noise. Frost filter follows formula given by

DN = $\sum_{n\times n} K \propto e^{-\alpha|t|}$

Where,

$$\alpha = \left(\frac{4}{n\bar{\sigma}^2}\right)\left(\frac{\sigma^2}{\bar{I}^2}\right)$$

$|t| = |x - x_0| + |y - y_0|$

K=Normalized constant

$\bar{I}$=Local mean

σ=Local variance

$\bar{\sigma}$=Image coefficient of variation value

n =moving kernel size [14]

Lee Refined:

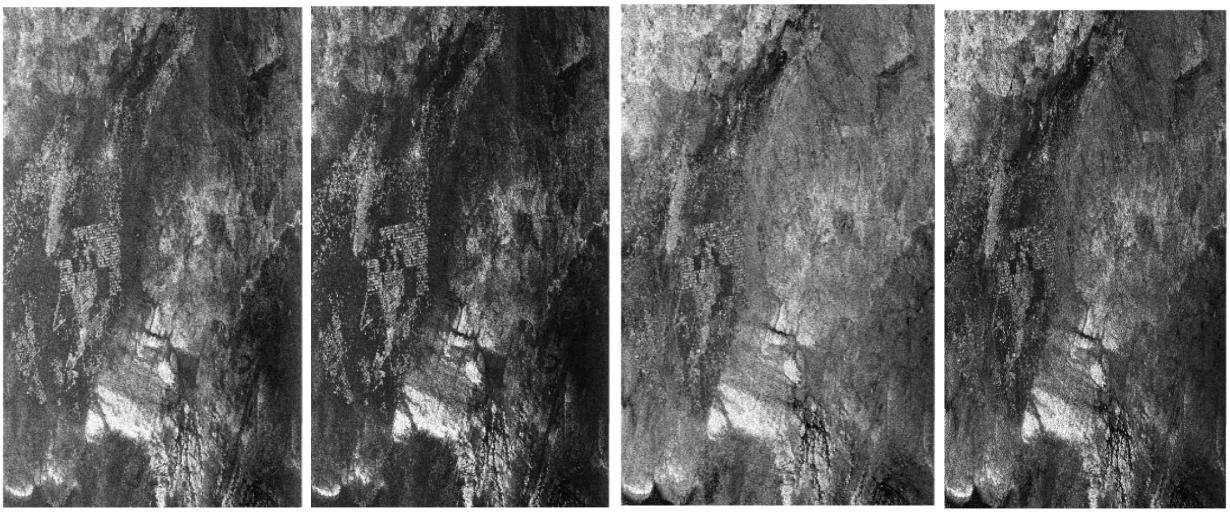
Refined Lee Filter is an enhancement of Lee filter and can preserve prominent edges, linear features, point target, and texture information. Lee Refined Filter– This filter was designed to overcome the drawback of edge boundaries that are left noisy by Lee filter. To improve filtering, once an edge is detected in a 7×7 sliding window, the algorithm uses the local gradient to estimate its orientation. Eight edge-directed non-square windows are allowed. The estimation of the local mean and of the local variance are performed within the local window that better fits the edge orientation. If no edge is detected, the estimates are computed on the whole 7×7 window. Filtering results are quite impressive, particularly on edges and high contrast areas. Some artifacts may occur when the filter processes textured areas that result to be overly segmented. Another limitation is that the filter works with a window of fixed size 7×7: textures characterized by a high spatial variation and thin linear features may be altered [17].

IDAN:

Intensity Driven Adaptive Neighborhood (IDAN) filter, is an adaptive filter technique where a neighborhood is formed using region growing method around each pixel. The advantages of the IDAN algorithm as compared to the other filters, is that the selected pixels are not required to lie within a fixed moving window. Fixed neighborhood speckle reducing techniques are less effective for variations in feature size and shape [18].

Result and Discussion

Step 1: Input images: SENTINEL-1 SAR data Input/Raw Image:

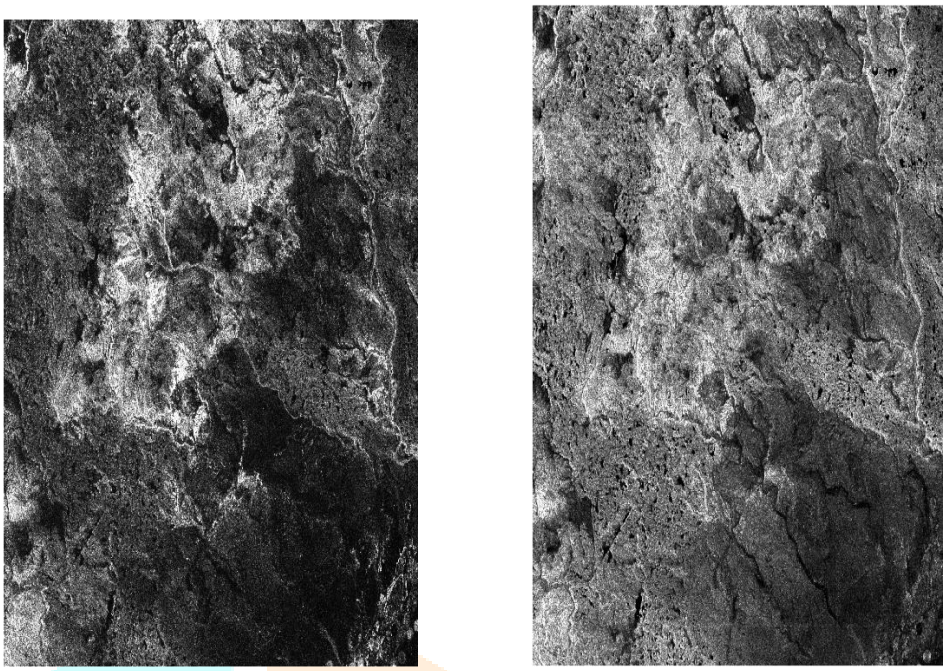


(a) (b) (c) (d)

figure 1: Raw Data (a) Amplitude_VH, (b)Intensity_VH, (c) Amplitude_VV, (d) Intensity_VV

Step 2: Images of Sentinel-1 SAR dataset of Various Filters Filtered Images:

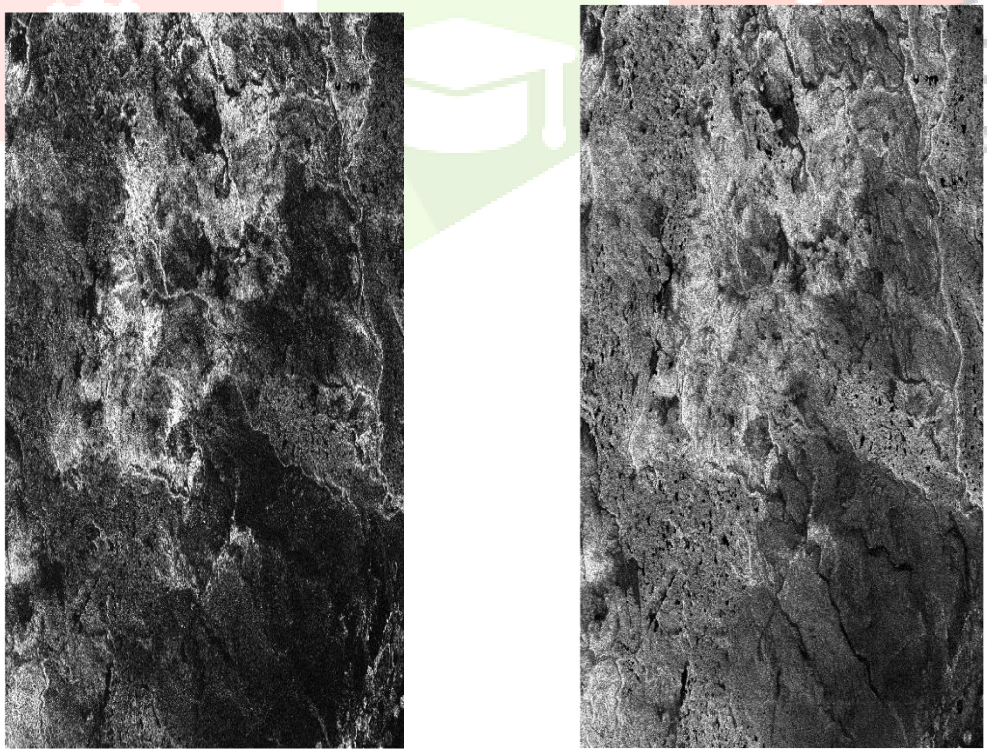
(i) Boxcar filter



(a) Sigma0_VH **(b) Sigma0_VV**

figure 2: Boxcar filtered image (a) Sigma0_VH and (b) Sigma0_VV

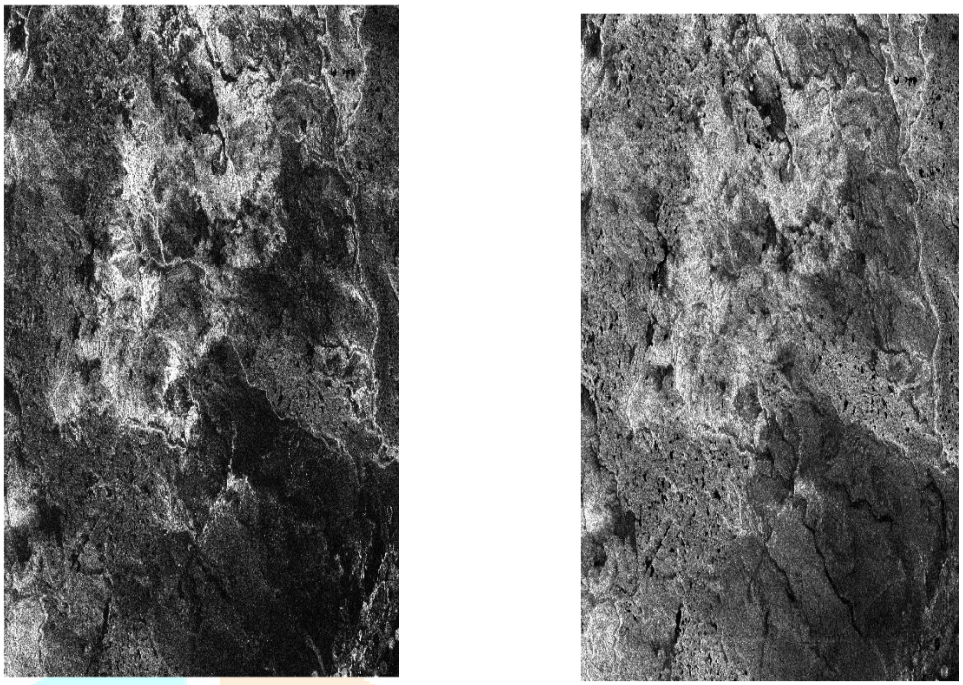
(ii) Median filter



(a) Sigma0_VH **(b) Sigma0_VV**

figure 3: Median filtered image (a) Sigma0_VH and (b) Sigma0_VV

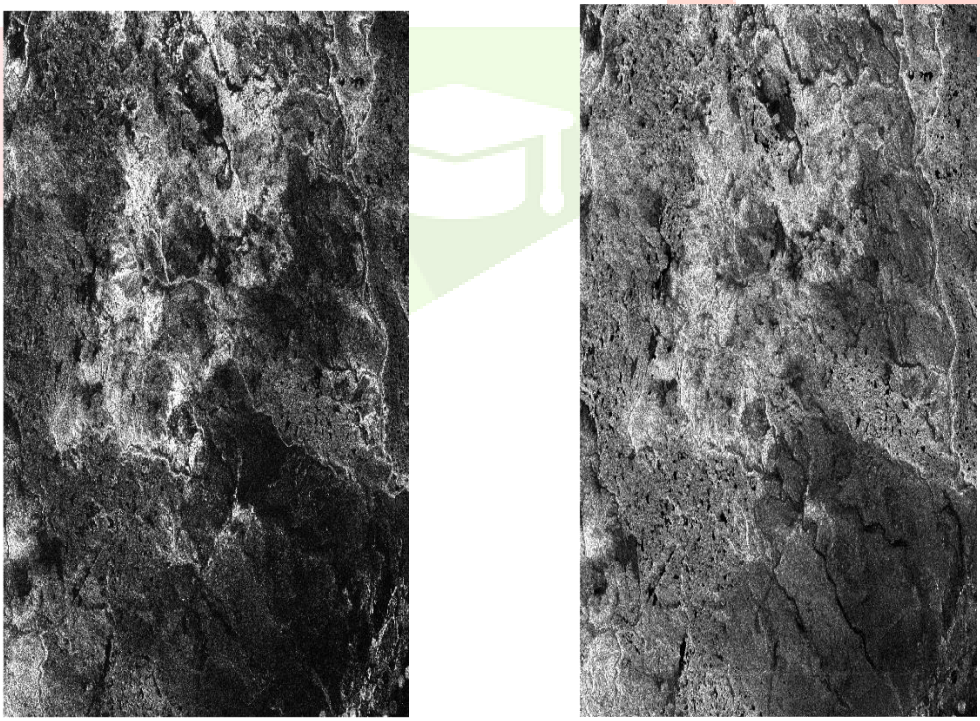
(iii) Lee filter



(a) Sigma0_VH **(b) Sigma0_VV**

figure 4: Lee filtered image (a) Sigma0_VH and (b) Sigma0_VV

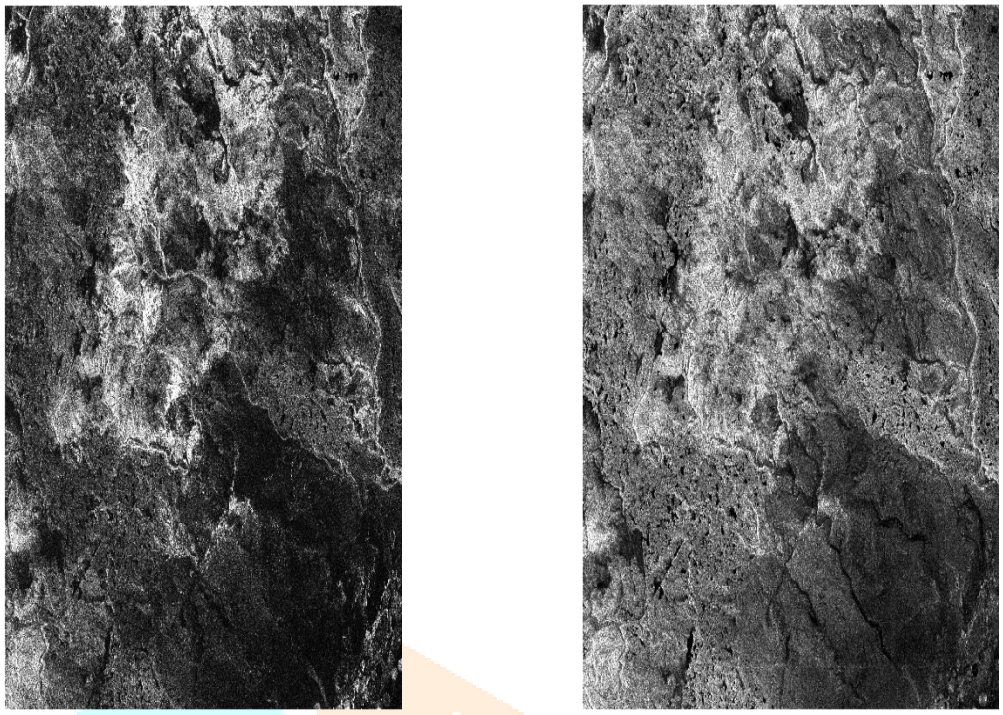
(iv) Gamma map filter



(a) Sigma0_VH **(b) Sigma0_VV**

figure 5: Gamma map filtered image (a) Sigma0_VH and (b) Sigma0_VV

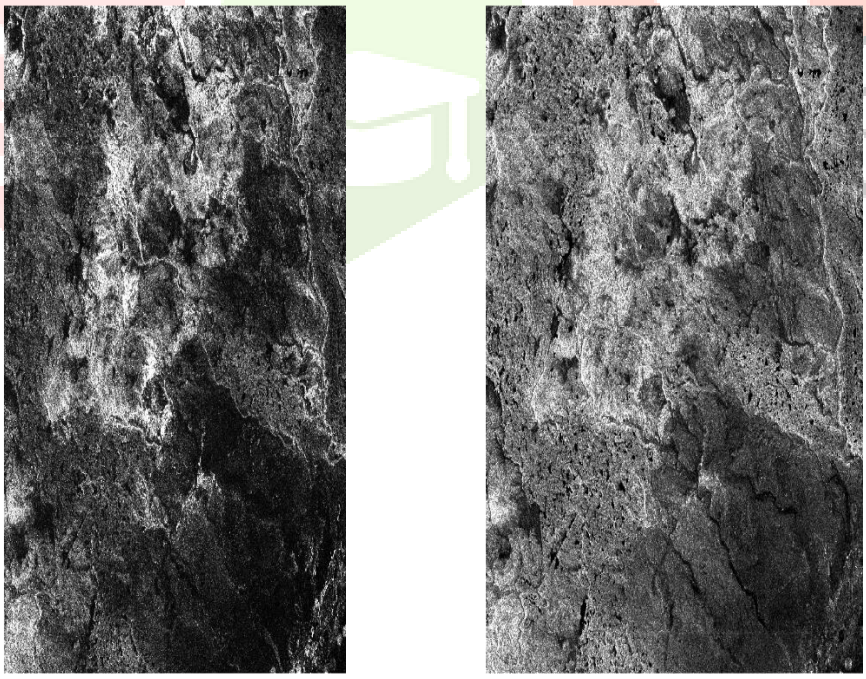
(v) Frost filter



(a) Sigma0_VH **(b) Sigma0_VV**

figure 6: Frost filtered image (a) Sigma0_VH and (b) Sigma0_VV

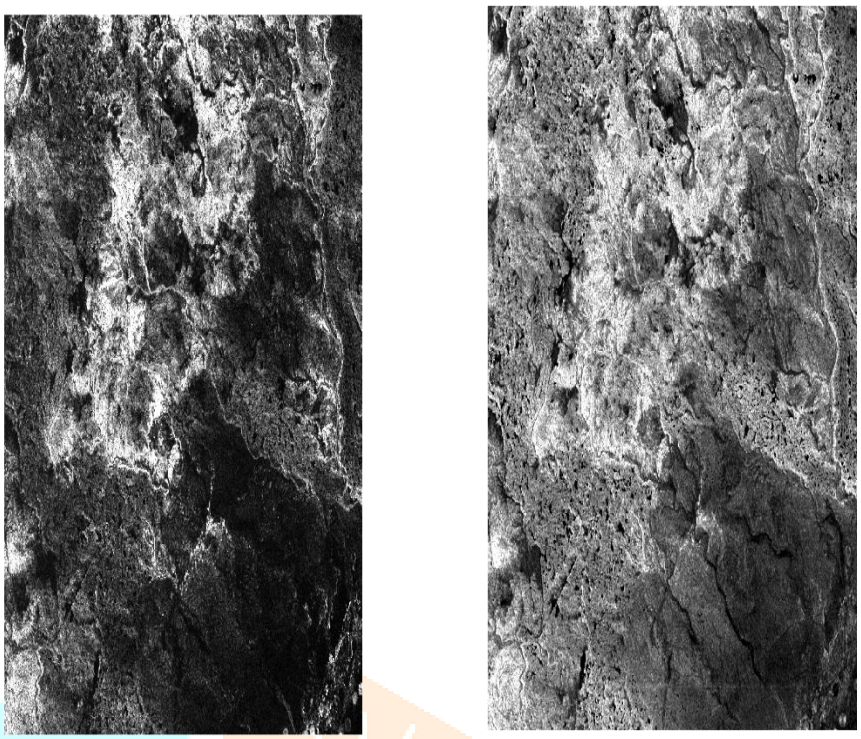
(vi) Refined Lee filter



(a) Sigma0_VH **(b) Sigma0_VV**

figure 7: Refined Lee filtered image (a) Sigma0_VH and (b) Sigma0_VV

(vii) IDAN filter



(a) Sigma0_VH **(b) Sigma0_VV**

figure 8: IDAN filtered image (a) Sigma0_VH and (b) Sigma0_VV

Step 3: Statistical measures
Statistical Parameters:

Standard Deviation (SD) / Sigma: Standard deviation is denoted by σ, it is used to measure quantify the amount of variation/ dispersion of a set of data values and also used in statistical conclusions. A low standard deviation means that the data points close to the mean or also called the expected value of the set and high means the data points spread out over a wide range of values [6].

$S = \sqrt{\sum(x - x')2/n - 1}$

Coefficient of Variation (CV): This is also called as Standard deviation to mean ratio (SD/M) which is well known quantitative measure for evaluating the level of smoothing in homogenous area. Lower value of CV represents good speckle noise reduction.

$C.V. = \sqrt{[x]/[x']}$

Mean Square Error (MSE): Mean Square Error is defined as (x, x') = E [(x - x') ^{2}]. Where x and x' represents original and filtered images respectively, [·] denotes statistical mean. The highest value of MSE represents original and filtered images are not similar and lowest value represents better image quality of the filtered image. MSE based measurements are useful to obtain a global performance assessment on the whole image, but usually they yield little information about the preservation of specific features, for which other indexes can be used.

Equivalent Number of Looks (ENL): The equivalent number of looks (ENL) was applied to measure the degree of suppression, which was defined as the square ratio of the mean to the standard deviation values in a homogeneous region. The larger the ENL was, the better the quality of the speckle reduction was. The ENL is another good indicator to show speckle noise reduction. The ENL for intensity image is defined as $1/\beta^2$ and for amplitude image is defined as ENL (A) = $(0.522/ \beta^2)$ [3][4][13].

Statistical Analysis of Input Image:

Table 1: The Statistical data of Input image SAR Dataset of sentinel-1 Satellite

	Amplitude VH	Intensity VH	Amplitude VV	Intensity VV
Pixel Total	20194207	20194207	20194207	20194207
Min	8.0000	64.0000	16.0000	256.0000
Max	446.0000	198916.0000	1082.0000	1170724.0000
Mean	66.8608	4956.1435	184.6422	37946.2417
Sigma	22.0402	3641.6179	62.0766	26621.8938
Median	63.8405	4061.0221	177.8769	31746.5921
Coefficient Variance	0.7348	0.7348	0.7016	0.7016
ENL	1.8522	1.8522	2.0317	2.0317
Max. Error	0.4390	198.8520	1.0670	1170.4680

Statistical Analysis of Output Image:

Table 2: Analysis of the Statistical data of Output image SAR Dataset of sentinel-1 Satellite

Statistical Parameter	Filter →	Box-car	Median	Lee	Gamma Map	Frost	Lee Refined	**IDAN**
Sigma	Sigma0_VH	0.0067	0.0066	0.0067	0.0067	0.0067	0.0063	**0.005**
	Sigma0_VV	0.0515	0.0514	0.0516	0.0516	0.0518	0.0498	**0.0399**
Median	Sigma0_VH	0.0057	0.0051	0.0059	0.0057	**0.0058**	0.0056	0.0052
	Sigma0_VV	0.0765	0.0719	0.0757	0.0767	0.0758	0.0751	**0.0775**
Coefficient Variance	Sigma0_VH	0.8519	0.8909	0.8549	0.8581	0.8669	0.8416	**0.7341**
	Sigma0_VV	0.5948	0.6151	0.5963	0.5977	0.5992	0.5902	**0.4849**
ENL	Sigma0_VH	1.378	1.2599	1.3682	1.358	1.3306	1.4118	**1.8558**
	Sigma0_VV	2.8269	2.6427	2.8122	2.7995	2.7854	2.8704	**4.2533**
Max. Error	Sigma0_VH	2.85E-04	2.67E-04	2.85E-04	2.85E-04	2.88E-04	2.95E-04	**1.40E-04**
	Sigma0_VV	0.0017	0.0019	0.0017	0.0017	0.0018	0.0016	**8.09E-04**

Step 4: Compare the results

Result and Discussion:

In this paper comparison between various filters such as Boxcar, Median, Lee, Gamma map, Frost, Refined lee and IDAN to remove speckle in multi-look SAR image Sentinel-1 GRD datatype is used. The results of these mentioned filters are analyzed and the implicated of statistical parameters it includes Mean, Median, Standard Deviation, Coefficient Variance and Equivalence Number of Looks (ENL) are compared. Evaluated the performance of statistical parameter of these filters, they are computed and provided comparative simulation model results of filters using SNAP ver. 8.0 software.

In step 1(input), figure 1 shows the Raw/ input Data image (a) Amplitude_VH, (b) Intensity_VH, (c) Amplitude_VV, (d) Intensity_VV,

In step 2(pre-processing), figure 2 shows the Boxcar filtered image (a) Sigma0_VH and (b) Sigma0_VV, Figure3 shows the Median filtered image (a) Sigma0_VH and (b) Sigma0_VV, figure 4 shows the Lee filtered image (a) Sigma0_VH and (b) Sigma0_VV, Figure5 shows the Gamma map filtered image (a) Sigma0_VH and (b) Sigma0_VV, figure 6 shows the Frost filtered image (a) Sigma0_VH and (b) Sigma0_VV, figure 7 shows the Refined Lee filtered image (a) Sigma0_VH and (b) Sigma0_VV and figure 8 shows the IDAN filtered image (a) Sigma0_VH and (b) Sigma0_VV and Table1 shows the Statistical data of Input image & Table 2 shows the analysis of the Statistical data of Output image SAR Dataset of sentinel-1 Satellite.

In step 3 Using statistical parameter (standard deviation (Sigma), median, coefficient variation (C.V.), equivalent number of looks (E.N.L.) and Maximum error) analyzed and compared the various filters. In Ideal case mean should be close to unity and standard deviation (sigma) should be as low as possible, lower value of CV represents good speckle noise reduction, the higher value for ENL and lower value of maximum error represents good noise reduction technique for a well performing filter. Here using high resolution Sentinel-1 dataset, its ENL should be approximate 4.4. Therefore, In table 2 represents standard deviation (sigma) low [Sigma0_VH(0.005) & Sigma0_VV(0.0399)] in IDAN filter. lower value of coefficient variation (C.V.) [Sigma0_VH(0.7341) & Sigma0_VV(0.4849)] in IDAN filter. Higher Equivalence Number of Looks (ENL) should approximate 4.4 [Sigma0_VH(1.8558) & Sigma0_VV(4.2533)] in IDAN filter and lower value of maximum error [Sigma0_VH(1.40E-04) & Sigma0_VV(8.09E-04)] in IDAN filter. then conclude that the IDAN (sigma0_VV) in figure 8 is better than Boxcar, Median, Lee, Gamma map, Frost, Lee refined filters and finally get the noiseless or noise reduction result of given dataset.

Conclusion:

Images are low noisy or restore when Coefficient Variance (CV), Maximum error is decreases (low) and ENL should be increases (high). Using output statistical analysis conclude that, IDAN filter is better than the Boxcar, Median, Lee, Gamma map, Frost, Lee refined single product speckle filters. IDAN (Sigma0_VV) figure 8(b) image is noiseless or more/good speckle noise reduction using Sentinel-1 satellite dataset using SNAP software.

References:

[1] Jensen R J (2014). Remote Sensing of the Environment an Earth Resource Perspective (2nd ed.) Pearson

[2] R. C. Gonzalez, Woods, R. E., 2002. Digital Image Processing, Addison-Wesley Inc.

[3] Nupur Saxena and Neha Rathore, "A Review on Speckle Noise Filtering Techniques for SAR Image" International Journal of Advanced Research in Computer Science and Electronics Engineering(IJARCSEE) Vol. 2,Issue 2, Feb.2013 ISSN:2277-9043.

[4] Jagtap Pornima Ramesh,, Sayyad Shafiyoddin Badruddin and Khirade Prakash Waghji, Comparative study of Gaussian and Boxcar filter of TerraSAR-X Data Image Using POL-SAR For Speckle Noise Reduction, International Journal of Recent Scientific Research Vol. 9,Issu,5(G),pp. 26977-26980,May 2018.

[5] https://www.l3harrisgeospatial.com/docs/adaptivefilters.html#Lee

[6] github.com, Ffilipponi Repository—Sentinel-1_GRD_Preprocessing: Standard Workflow for the Preprocessing of Sentinel-1 Satellite Data. Available online: https://github.com/ffilipponi/Sentinel-1_GRD_preprocessing.

[7] Sentinel-1 Dataset downloads from, https://scihub.copernicus.eu/dhus

[8] SNAP Software, Help Document 2019. Available on https://step.esa.int/main/toolboxes/snap

[9] Andreas Braun, Luis Veci Sentinel-1 Toolbox, SAR Basics Tutorial, Updated March 2021,http://step.esa.int/docs/tutorials/S1TBX%20SAR%20Basics%20Tutorial.pdf

[10] S. Medasan and G. Umamaheswara, Analysis and Evaluation of Speckle Filters for Plarimetric Synthetic Aperture Radar (PolSAR) Data Reddy International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 15 (2017) pp. 4916-4927 © Research India Publications. http://www.ripublication.com 4916.

[11] Federico Filipponi, Sentinel-1 GRD Preprocessing Workflow, Proceedings 2019, 18, 11; doi:10.3390/ECRS-3-06201, https://www.mdpi.com/2504-3900/18/1/11/pdf

[12] Carlos Lopez-Martinec,Eric Pottier, SAR data Statistical and Speckle Noise Filtering, DLR,PolSARpro tutorial.

[13] Khirade P.W., Jagtap P.R., Sayyad S.B., Comparative Study of Different Filters of RADARSAT-2 using PolSAR for Speckle Noise Reduction, Aarhat Multidisciplinary International Education Research Journal(AMIERJ), Volume-VII, Special Issue-XXIII, ISSN-2278-5655, 27th May 2018.

[14] Y. Yu, Scott T. Action, "Speckle Reducing Anisotropic Diffusion" IEEE Trans. on image processing , vol. 11 Nov. 2002

[15] T. Huang, George J. Yang and Gregory Y. Tang, "A Fast Two Dimensional Median Filtering Algorithm" IEEE Trans. on Acoustics, Speech and signal processing, vol. ASSP-27, no. 1 Feb. 1979.

[16] D. A. Nelson Mascarenhas, "An Overview of Speckle noise filtering in SAR images." European Space agency. Provided by the NASA Astrophysics Data System.

[17] Jong-Sen Lee, "Refined filtering of image noise using local statistics," Comput. Graph. Image Process., vol. 15, no. 2, pp. 380–389, Apr. 1981.

[18] Sivasubramanyam Medasani and G. Umamaheswara Reddy, "Analysis and Evaluation of Speckle Filters for Polarimetric Synthetic Aperture Radar (PolSAR) Data" International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 15 (2017) pp. 4916-4927 © Research India Publications. http://www.ripublication.com

[19] https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-1-sar (Sentinel-1 user guide)

[20] Wahyu Hendardi Giri Ananto1 , Ade Febri Sandhini Putri1 , Haeydar Anggara Hadi1 , Difa Nisrina Hanum1 , Bayu Kurnia Puji Wiryawan1 , Rifqi Rizaldy Prabaswara1 , Sanjiwana Arjasakusuma, "Performance of Various Speckle Filter Methods in Modelling Forest Aboveground Biomass using Sentinel-1 Data: Case Study of Barru Regency, South Sulawesi", Sixth Geoinformation Science Symposium, edited by Sandy Budi Wibowo, Andi B. Rimba Stuart Phinn, Ammar A. Aziz, Proc. of SPIE, Vol. 11311, 113110P · © 2019 SPIE CCC code: 0277-786X/19/$21 · doi: 10.1117/12.2549036 Proc. of SPIE Vol. 11311 113110P-1

[21] Pornima Jagtap, Sayyad Shafiyoddin, "Statistical Analysis of Lee Filter of SAR Dataset of sentinel-1 Satellite for Speckle Noise Reduction" International Journal of All Research Education and Scientific Methods (IJARESM), ISSN: 2455-6211 Volume 9, Issue 12, December-2021, Impact Factor: 7.429, Available online at: www.ijaresm.com