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Towards Identifying Optimal Quality Indicators for Evaluating De-Noising Algorithm Performance in SAR

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Abstract: Synthetic Aperture Radar data processing from the raw signal entails a series of complex steps to arrive at the visible image. The final image is always tarnished with a specific kind of noise known as speckle noise. Speckle noise is multiplicative in nature and makes the image radio metrically poor and the contrast is heavily affected. Hence such images cannot be directly used for further applications involving classification, segmentation, texture analysis, or even object identification, unless and until some filtering is performed on them. Standard filters available for dealing with additive Gaussian noise present in optical images, are not effective here. So special filters using both adaptive as well as non adaptive techniques to assess the noise and remove it, are used. In this paper some of the popular adaptive filters are studied and applied on high resolution data sets from RISAT-1 mission. Both radiometric as well as geometric quality is evaluated on typical areas to arrive at the optimal quality indicators for de-noising such SAR data.

Keywords: SAR, speckle noise, denoising, calibration, radar cross section, radiometric resolution, geometric resolution, impulse response function, ISLR, PSLR, Mean Square Error(MSE), S/MSE, Speckle index .

1. INTRODUCTION

Synthetic Aperture Radar (SAR) imaging has become a popular means of acquiring remote sensing data by Earth Observation Satellite(EOS) sensors all across the world due to its all weather and day and night capability. The basic geometry of SAR and its active mode of signal acquisition, entails a very complicated sensor design, signal processing, image processing and its interpretation[1]. The fundamental theory behind SAR needs transmission and reception of linearly frequency modulated chirp signals, and Doppler processing of the encoded returned echo. Coherent signal processing is done to attain high spatial resolution. However due to this coherent nature of signal, a grainy type of noise is inherent in the image, which degrades the radiometric quality of the data. This is known as speckle noise[1][2][3][4]. Noise characteristics of SAR images differ from those of optical images due to the inherent coherent nature of SAR signal processing. The speckle noise which is generated in SAR images is multiplicative in nature[1][4]. A number of techniques have been developed during the recent times for the speckle noise removal from SAR images. Noise removal techniques, however, tend to improve the radiometry of the images at the cost of geometry. Hence a need to quantify the performance of an algorithm performance in terms of quality metrics capturing both the radiometric as well as the geometric qualities is crucial.

SAR data is unique in its characteristics, and is different from the visible images which are obtained by optical sensors. SAR utilizes the microwave band in the Electromagnetic Spectrum, to image the scene of interest. Thus the frequencies used, are in the lower frequency zones mostly in the 1-10 GHz region. Microwaves have special properties that are important for remote sensing. Because of their longer wavelengths, compared to the visible and infrared bands, microwave radiation can penetrate through cloud cover, haze, dust, and all but the heaviest rainfall**,** as the longer wavelengths are not susceptible to atmospheric scattering which affects the shorter optical wavelengths. Its capability to image even during night is another added feature. This allows detection of microwave energy under almost all weather, at all time and all environmental conditions. The relatively good spatial resolutions of modern day spaceborne SAR sensors of around 3m, and better, have furthered the scope of different applications. However the potential application in the areas of agriculture, land use type discrimination, forest biomass estimation, geology, flood mapping, disaster zone mapping, marine biology etc. is affected due to the inherent speckle noise in the data. Due to the noise, the accuracies of image analysis tools involving classification, segmentation, target detection etc get reduced. Apart from that, the automated means of target detection, clustering etc become less efficient, and the end applications suffer[3][4][5].

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SAR data, as opposed to optical images need to be pre-processed in order to get an image. This process involves complex data processing in two dimensions, which are known as the range and the azimuth directions, before a focussed image is obtained. Development of new algorithms for SAR raw data processing for getting well focussed images and with good phase fidelity is itself a research area. Several such algorithms are already in existence, such as the Range-Doppler algorithm, Chirp_scaling algorithm, SPECAN algorithm, Wave number domain algorithm[1][5][6]. Geometric focussing is achieved by the processing algorithm, whereas the radiometric quality is ensured by antenna pattern correction by using calibration data from controlled experiments. Multilook processing technique[5][1], is also resorted to reduce noise. These are part of the signal processing operation before an image is generated. SAR image quality parameters are used to estimate the geometric and radiometric quality of the processed data. Geometric quality which has similar effects as blurring and defocusing of optical images, can however, be assessed by some typical SAR quality parameters. This involves the deployment of accurately designed point targets called corner reflectors(CR)[7][8]. SAR response to the point target, assuming negligible background scattering and thermal noise, is referred to as Impulse Response Function(IRF)[8]. The analysis of the IRF gives quality indicators related to the spatial resolution and the presence of undesired sidelobes which degrade the contrast of the image[9]. Radiometric quality of SAR image is mostly evaluated by using the well known quality parameters of radiometric resolution, equivalent number of looks(ENL), signal to mean square error(S/MSE) and speckle index(SI), as are reported in literature[9][10]. These are assessed through statistical analysis of regions with constant backscattering coefficients, such as the mangrove forests of Sunderban, Amazon rain forests of Brazil etc[1]. Radiometric quality is given by the cleanliness of the final image, while geometric quality indicates the sharpness of the image. A plethora of denoising filters exist as of today in the spatial domain[11-15][7]. In the wavelet domain several homomorphically treated SAR images are filtered using various wavelet based filters[16][17]. However any attempt to improve the SAR radiometric quality has a negative impact on the geometric quality. In general the quality parameters which have been used by the image processing community for denoised image evaluation are the radiometric quality of signal to noise ratio (SNR) and mean square error(MSE)[8][18]. But these quality parameters are not necessarily sufficient for evaluating SAR images, since the spatial resolution degradation and geometric fidelity of targets are not considered in these evaluation methods. In this paper quality indicators are being evaluated on different speckle filtered images and on different types of data sets from fine resolution images of RISAT-1 SAR in order to arrive at the optimal quality parameters which may be necessary and sufficient to evaluate the image quality. The aim of this paper is to analyse suitable metrics to quantify the performance of noise removal algorithms for SAR images, such as those from high resolution(3m) data from RISAT-1 SAR. Poorer resolution SAR images of ERS and ENVISAT(25m), posed different kind of image quality, which is not sufficient for the current generation high resolution data. The quality indicators with respect to impulse function response and uniform area are described in detail, in section 2. In section 3 we analyse the performance of different algorithms on a few selected RISAT-1 SAR images in terms of different quality metrics, to arrive at the optimal quality metrics.

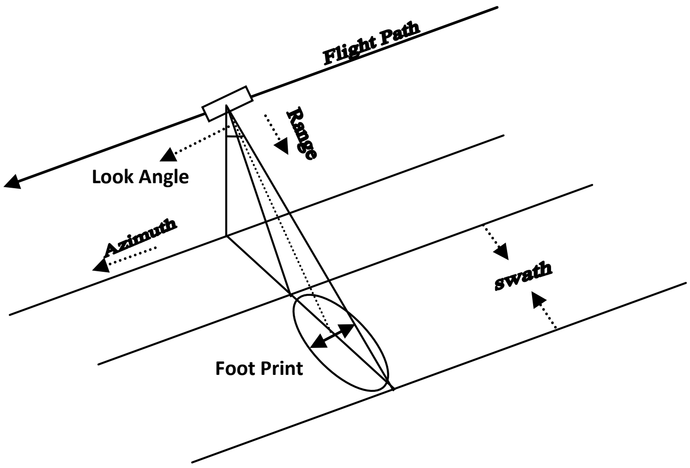

Fig1: Space-borne SAR Geometry

2. QUALITY METRICS FOR SAR

SAR signal processing is performed on the returned signals from the radar illuminated targets. It involves elaborate steps such as range compression, Doppler Centroid Estimation, range cell migration correction and azimuth compression before the detected intensity image can be generated. The image value at each sample is a function of the radar cross section (RCS), σ, which is a measure of the backscattering coefficient of the illuminated target. Each sample has an amplitude α(x,y) and a phase ϕ(x,y). Radar backscatter signals are determined by the physical characteristics of surface features such as the surface roughness, geometrical structures, the orientation of the objects with respect to the radar boresight direction etc. Apart from that the signal is also a function of the frequency of the transmitted radar signal and its polarization which can be VV, HH, VH or HV. The basic geometry of radar transmission and reception of the signal is illustrated in Fig.1

The signal power for the SAR image is given by:

$$I(x,y) = \gamma(x,y) * \eta(x,y) \quad (1)$$

Where I is the intensity, γ is the RCS and η is the speckle noise[1][2].

Speckle noise is a phenomenon in coherent imaging systems such as SAR, MRI(Magnetic Resonance Imaging) etc. A fully developed speckle (i.e. when the number of scatterers is large in one resolution cell) has the characteristics of a random multiplicative noise, as discussed by Gagnon et al[17]. The noise intensity is generally found to follow Gamma distribution[1]. Hence radar signal analysis needs an entirely different domain of understanding compared to the normal analysis methods employed for optical images.

Generally a uniform area is chosen to estimate the speckle noise, which is actually signal dependent. This gives the radiometric quality of the image. However, this does not give any idea about the degradation in the geometric quality of the image. SAR data is calibrated using man made CR, which are specifically designed and deployed for data analysis and calibration. A corner reflector behaves like a point target with well defined sidelobes and a mainlobe, which can be analysed. A typical target response from a CR is shown in Fig 2.3. Different quality parameters for SAR image for radiometric quality evaluation are generally assessed from a relatively uniform area. The definition of uniform area is also not the same as that in optical images. In the case of optical or visible images, an uniform area is characterised by almost the same gray values or digital numbers. SAR being a coherent system does not have such a characteristic. The backscattering coefficients for a homogeneous area in SAR will be randomly varying which is due to the presence of speckle noise. So the only means of selecting a uniform area is by visually inspecting the data and perhaps by using the ground truth of the selected areas. For example a bare field with a flat surface or the well known mangrove areas of Sunderban with same backscattering response across the swath, are suitable uniform areas. Similarly a water body with no ripple or wind over it is a potential uniform zone. These types of targets are generally known as extended targets [1].

In optical images normally the mean square error(MSE) and the sharpness criteria are the well known quality evaluation parameters, assuming that the original images can be estimated. SAR being a coherent imaging system, which goes through complex signal processing steps before an image is obtained, needs different quality metrics which are briefly described in the following sections.

Two types of features, namely extended targets and artificial point targets using Corner Reflectors(CR) are used for SAR image quality evaluation. Extended targets are supposed to have same backscattering coefficient, The radiometric parameters which are used to evaluate the images are signal to noise ratio(SNR), Speckle Index(SI), Equivalent Number of Looks(ENL), S/MSE and radiometric resolution. SNR is defined as the ratio of the mean and the standard deviation of a small uniform area. SI which is a derived parameter depends on the SNR. Radiometric resolution which is also a derived parameter is a standard method of looking at the radiometric quality of a SAR image. Any noise removal technique is aimed at reducing this number. Typically for RISAT-1 single look raw image, it is about 3.5dB, and the aim of denoising is to reduce it to about 1.5 dB.

Quality parameters based on extended targets are discussed in section 2.1. Quality parameters for point targets are discussed in section 2.2

2.1 Quality Parameters From Extended Targets

The mean preservation and fluctuation reduction in homogeneous region are measures of success in terms of radiometric estimation. A successful speckle reducing filter will not significantly alter the mean intensity within a homogeneous region[19][20]. The effect of variance reduction while preserving the mean value of a uniform region is an indicator of noise reduction. For evaluating the quality of an image in terms of radiometry, usually a small homogeneous area is selected and the quality metrics is evaluated for it, as is shown in Fig2.1.

Fig2.1: Extracted Homogeneous region from the rural image

The quality metrics parameters are given in [9] and [18] and are elaborated below

Radiometric Resolution

Radiometric resolution for a SAR image is estimated from a uniform area by estimating its standard deviation and mean. The formula used for evaluating this is given by:

$$\gamma = 10\log_{10}(1+\sigma/\mu) \qquad (2)$$

Where μ is the mean value and σ is the standard deviation of the extended target area.

Lesser the γ value, better is the image quality in terms of noise suppression. For a single look SAR image the nominal value of γ is around 3.5dB.

ENL

ENL is the equivalent number of looks for a SAR image. Higher this factor better is the speckle suppression. It is given by:

$$\xi = \mu^2/\sigma^2 \qquad (3)$$

Multilook algorithms used for raw SAR data processing[12][13][17][20], split the azimuth spectrum into three or four smaller bandwidth zones, process them independently, and subsequently incoherently add these data to produce denoised images with better radiometric quality. The factor of improvement in ENL for this method is by $1/\sqrt{L}$, where L is the number of looks.

SNR

SNR is the signal to noise ratio for a SAR image, which is estimated by selecting homogeneous regions such as bare fields. Higher this factor better is the speckle suppression. It is given by:

$$\zeta = \mu/\sigma \qquad (4)$$

S/MSE

$$S/MSE = 10\log_{10}[(\Sigma I_{in}^2)/(\Sigma I_{out}^2 - \Sigma I_{in}^2)] \qquad (5)$$

where I_{in} is the noise free image, and I_{out} is the output image.

It is to be noted that S/MSE need an ideal noise free image for its evaluation and hence is not suitable for SAR type of images.

Speckle Index

Speckle index is given by the ratio of the normalized standard deviations of the image after and before filtering. It is given by:

$$\psi = (\sigma_f/\mu_f) * (\mu_m/\sigma_m) \qquad (6)$$

where σ_f and σ_m are the standard deviation of filtered and non filtered images, and μ_f and μ_m are the mean filtered and non filtered images, for the selected uniform areas.

The most popular quality indicators for SAR images which have been reported in various research journals are those of SNR, ENL, and S/MSE [5][7][14][17]. However, from the point of SAR image quality, the most suitable quality parameter for evaluating the radiometric quality of an image is generally radiometric resolution, due to the reasons elaborated above.

2.2 Quality Parameters Based On Point Targets

Corner reflectors(CR) are designed with proper shape and size in order to get the maximum returned signal from the SAR transmitted signal falling on them. These are of different types viz. square dihedral and trihedral or triangular type dihedral and trihedral or even circular trihedral, with sizes varying from 60cm to about 1.5m for evaluating C band SAR data. The area where the corner reflectors are deployed are usually flat bare fields devoid of any vegetation, which can give uniform background signature with minimum backscatter. SAR processed images are used for carrying out the data quality analysis for the extracted zones surrounding the deployed corner reflectors, in order to evaluate the quality of processing.

Geometric quality parameters are derived from the impulse response functions obtained from the CR data sets. For assessing the geometric quality of the image the normal method is to take a point target which is surrounded by a uniform low intensity background area. The impulse response function(IRF) of such a target is extracted in the two directions of range and azimuth. The IRF for one such CR which was used for our study, is shown in Fig2.3(a) for the range direction. The 3D IRF in the linear domain is shown in Fig2.3(b). The IRF in the azimuth and range directions are analysed to get the various image quality parameters as mentioned below.

CR simulates a point target and the quality metrics are evaluated using the following parameters and is used for tuning the processing algorithm, viz. geometric resolution, ISLR, PSLR etc. As is seen from the definition, ISLR, PSLR give the contrast and should not be disturbed unless one wants to enhance the image which is not the purview of this study. However it should be noted that these are important parameters to verify that the signal processing algorithm does not introduce any kind of bias.

Among the geometric resolution parameters, which are range and azimuth resolutions, the latter is fixed while the range resolution varies with the incidence angle to the target. It is poorer in the near range and improves at the far range. For RISAT-1 usually for middle beam at 36^0, the range resolution is around 2.5m. Usually multilook

processing is done to improve the radiometry at the cost of spatial resolution. Multilook with N looks, improves the radiometry by a factor of $1\sqrt{N}$, while the spatial resolution degrades by a factor of N[1][2].
The impulse response is converted from the linear domain to the logarithmic scale. The mainlobe gives the energy in the point target. The 3dB width of the mainlobe of the IRF gives the geometric resolution of a point target which is representative of the resolution of the processed image[8]. Broader the mainlobe, poorer is the resolution. The secondary lobes are known as the sidelobes. The energy present in the sidelobes should be minimal if a good image quality with a good contrast is desired. The contrast performance can thus be defined in terms of some other parameters which are known as integrated sidelobe ratio, ISLR and peak sidelobe ratio, PSLR. These are defined as:

PSLR
This is defined as the ratio of the peak intensity of the most prominent sidelobe nearest to the mainlobe to the peak intensity of the mainlobe. Since there are two sidelobes on two sides of the mainlobe, and normally the response function is not symmetric, as is desired for an ideal target, the largest of the two is taken as the value for the peak sidelobe ratio computation. The value is expressed in decibels. As the value is computed from the normalized ratio the logarithmic value is negative. Higher the magnitude value of this factor, better is the sidelobe suppression. For a well processed SAR data, a nominal value of -18dB to -22dB is considered to be a good quality indicator.

ISLR
This is defined as the ratio of the energy in the mainlobe to the energy in the sidelobes around the point target. The value is expressed in decibels. As per ESA's definition the power in the sidelobe is considered for a maximum of ten resolution cells side. Here too higher the magnitude value of this factor, better is the sidelobe suppression. For a well processed SAR data, a nominal value of -15dB to -18dB is considered to be a good quality indicator.
It is to be noted that both ISLR and PSLR are affected by the focussing and in general indicates the contrast of an image.

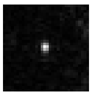

Fig 2.2 A single point target

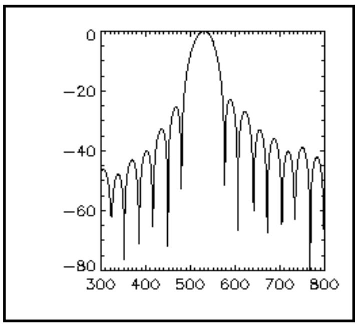

Fig2.3(a): IRF Of Point Target–Range Cut (Log domain)

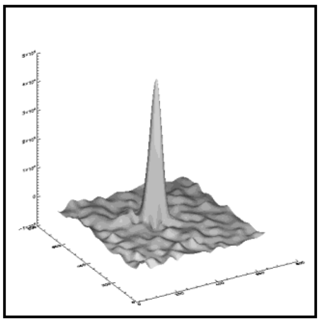

Fig2.3(b): IRF Of Point Target(3D) (Linear domain)

The most suitable quality parameters for geometry of SAR images are the range and azimuth resolutions. Aim of filtering of noise is to improve the radiometric resolution without degrading the geometric resolution. Several denoising filters are existing to do that for SAR images. So the ideal method of quality based filtering technique proposed is as follows:
For every noise removing algorithms, the radiometric resolution on homogeneous regions, and geometric resolution along range and azimuth cuts of the point target(CR) are estimated. Accordingly we have chosen two regions:

(a) Rural area near Ahmedabad for getting uniform areas in the fields, for radiometric resolution estimation.
(b) Point targets of deployed corner reflectors(CR) for geometric resolution estimation.

The candidate algorithms are of two kinds. One is the conventional spatial domain filters such as the Lee, Frost, Extended Lee, Extended Frost, Gamma_MAP, Kuan etc[11][12[13][14].

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The other method is the space-frequency domain filtering using, Daubechies wavelet based denoising with one level of decomposition[9]. The formulae for some of the spatial domain filters are given in Table2.1 as was shown by Huang et al[18].

Table2.1: Formula For Some Of The SAR Filters

Filter	Weighting Function	Filtering Formula
Box	$W(x,y)=\begin{cases}1 & \lvert x\rvert \le x_0 \quad \lvert y\rvert \le y_0 \\ 0 & otherwise\end{cases}$	$\hat{I} = I * W$
Median		$\hat{I} = \underset{\lvert x\rvert \le x_{00}, \lvert y\rvert y_0}{Median}(I(x,y))$
Lee	$W(x,y)=1-\frac{C_{si}^2}{C_I^2(x,y)}$	$\hat{I} = I\cdot W + \bar{I}(1-W)$
Frost	$W(x,y)=K_1 e^{-K_d C_I(x,y)\sqrt{x^2+y^2}}$	$\hat{I} = I * W$
Kuan	$W(x,y)=\frac{1-C_{si}^2 / C_I^2(x,y)}{1+C_{si}^2}$	$\hat{I} = I\cdot W + \bar{I}(1-W)$
Enh. Lee	$W(x,y)=e^{-K_d\frac{C_I(x,y)-C_{si}}{C_{max}-C_I(x,y)}}$	$\hat{I}=\bar{I} \quad C_I \le C_{si}$ $\hat{I} = I\cdot W + \bar{I}(1-W)$ $C_{si} < C < C_{max}$ $\hat{I} = I \quad C_I \ge C_{max}$
Enh. Frost	$W(x,y)=K_1 e^{-K_d\frac{C_I(x,y)-C_{si}}{C_{max}-C_I(x,y)}\sqrt{x^2+y^2}}$	$\hat{I}=\bar{I} \quad C_I \le C_{si}$ $\hat{I} = I * W \quad C_{si} < C < C$ $\hat{I} = I \quad C_I \ge C_{max}$
GMAP	where $k=\alpha-N-1$ $\alpha=\frac{1+C_{si}}{C_I^2-C_{si}^2}$	$\hat{I}=\bar{I} \quad C_I \le C_{si}$ $\hat{I}=\frac{k\bar{I}+\sqrt{\bar{I}^2k^2+4\alpha N\bar{I}}}{2\alpha}$ $C_{si} < C < C_{max}$ $\hat{I} = I \quad C_I \ge C_{max}$

3. DATA ANALYSIS

Two different types of data sets have been chosen for seeing the effects of filtering. These are:

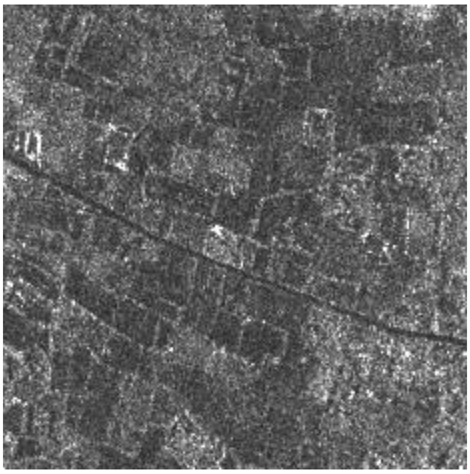
(a) First data set is in the rural Ahmedabad, having field regions with distinct boundaries, roads and different textures.

(b) Second data is selected to be an urban area in Ahmedabad where a few corner reflectors were deployed for RISAT-1 SAR data calibration and evaluation.

Filtered images have been used where Enhanced Lee, Enhanced Frost, GAMMA_MAP, and Daubechies wavelet based denoising algorithm have been applied on the 16 bit raw images of the areas selected.

3.1 Radiometric Resolution Evaluation For Raw Image

Homogeneous regions (32X32) from the single look raw image data from FRS-1 mode of RISAT-1 data were selected and the radiometric resolutions were calculated from those regions. Table1 highlights the results for 8 such regions within the scene and Figure 5 shows the plot for these. The estimated radiometric resolution of around 3.11 to 4.2 dB is observed, which is as per the theoretical value expected for a single look SAR data set.



Sr No	Region Number	Scanline	Pixel	Radiometric Resolution(dB)
1	1	1000	2000	4.20
2	2	1000	1000	3.69
3	3	1375	2064	3.11
4	4	1630	2000	3.22
5	5	2200	2200	3.57
6	6	2350	2330	3.40
7	7	2450	2330	3.68
8	8	500	500	3.95

Table3.1: Radiometric Resolution For Raw Image Data(Single Look)

Fig3.1: Extracted Image of Homogeneous Areas

3.2 Radiometric Resolution Evaluation For Filtered Images

For evaluating the radiometric resolution quality metrics one data of a rural scene near Ahmedabad is taken. The image is shown in Fig 3.2. The raw image and the filtered images using various spatial domain and one wavelet domain technique have been generated. An uniform area of size 32X32 is taken from these and used for estimating the radiometric resolution parameter. These are given in Table 3.2.

Table3.2: Radiometric Resolution For Filtered Image & Raw Data

Data Type	Radiometry	
	Mean	Rad Resoln (dB)
Raw	168.13	3.76
Enh Lee(3)	166.96	2.09
Enh Lee(5)	166.89	1.47
Frost(3)	166.60	2.14
Frost(5)	166.57	1.56
Enh Frost(3)	166.77	2.01
Enh Frost(5)	168.13	1.84
Gamma(3)	168.14	2.0
Gamma(5)	166.89	1.41
D4_Wavelet	167.82	2.56
D4_Wavelet+sm3	167.34	1.83

Fig 3.2 Ahmedabad Rural Area

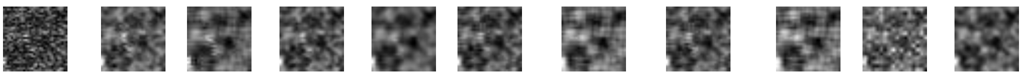


Fig3.3 Raw Enlee3 Enlee5 Frost3 Frost5 Enfrost3 Enfrost5 Gamma3 Gamma5 D4 D4_sm3

Here it is observed that *mean* value is almost the same as that of raw image, for all the filtered images, as is required for good image radiometric quality. Radiometric resolution parameter improves, with window size for spatial filters. Different filters' performance shows that the overall quality parameter of radiometric resolution is of similar value for all the filtering techniques used, with window size 3 and similarly for window size 5. However D4 with box car filtering with window size 3, give similar performance as that with window size 5 for spatial domain filters. Hence wavelet based technique is seen to give superior radiometric performance.

3.3 Geometric Resolution Evaluation For Raw Image

The following procedure was followed for finding the spatial resolution of the point targets: 32X32 pixels around one of the corner reflector points shown encircled in Fig 3.4 has been extracted for the CR data analysis. Fourier interpolation has been used to interpolate the data by 8 times. This is done to get better estimates of the 3dB beam width. The geometric resolution of the points has been estimated in the range and azimuth directions after linearly interpolating the points around the 3 dB zones from the targets. The estimated values have been given in Table 3.3. 3D IRF plot of one CR is shown in Fig 3.5(a).

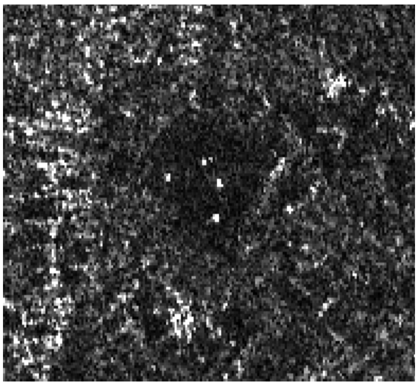


Fig3.4: Extracted Image of CR Area

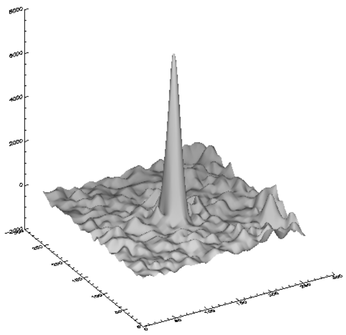


Fig 3.5(a) Point Target Response For Raw Image

Table 3.3: Estimated Spatial Resolution For Raw Image Data(3 CRs)

CR Nos	Resolution (m)	
	Azimuth	Range
T1	3.39	3.18
T2	3.72	3.04
T3	3.43	2.98

3.4 Geometric Resolution Evaluation For Filtered Image

From the above CR data sets shown in Fig 3.3, one CR has been chosen to evaluate the geometric quality metrics here. We have carried out the same exercise for other CR points also, but as they are almost the same we are not showing them in this paper. The range and azimuth cuts have been taken across the peak point of the IRF, and the spatial resolutions have been evaluated for the CR in the raw and the filtered images. This gives the geometric resolution before and after filtering. The results are tabulated in Table3.4

3D Impulse response Function for the CR for raw and filtered images are shown in Fig3.5 to see the geometric fidelity of the targets after filtering. SAR being very sensitive to target structure and geometry it is imperative to note that one of the most important criteria of noise filtering would be to reduce the noise, with minimal spatial resolution degradation, and without disturbing the geometric fidelity. This is brought out in the 3D plots of the point targets.

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Table 3.4: Estimated Spatial Resolution For Filtered Images & Raw Data(CR-2)

Data Type	Resolution (m)	
	Range	Azimuth
Raw	3.04	3.72
Enh Lee(3)	4.75	5.57
Frost(3)	4.61	5.39
Enh Frost(3)	4.64	5.41
Enh Frost(5)	5.17	6.67
Gamma(3)	4.79	5.34
Gamma(5)	5.28	7.29
D4_Wavelet	3.36	3.29
D4_Wavelet+sm3	4.96	5.59

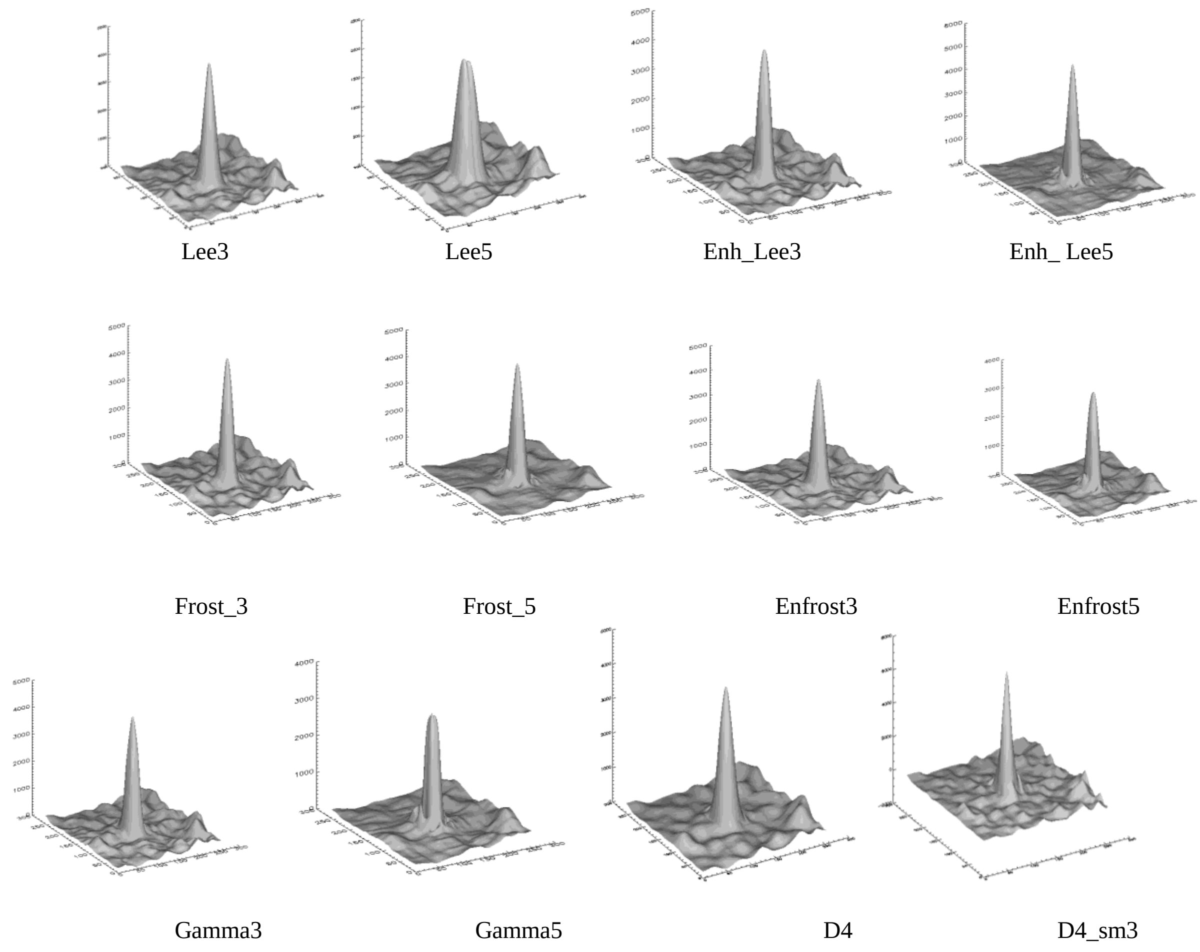

Fig 3.5(b) Point Target Response For Filtered Images

From the analysis carried out above, it is observed that filtering using spatial filters like Gamma-MAP, enhanced Frost and Lee give good radiometric resolution as well as geometric resolution. However the overall geometric fidelity is slightly degraded in these compared to the original. The wavelet based denoising quality metrics is comparable with the spatial filters, but also preserve the geometric fidelity as is shown from the 3D shape plots. It is imperative to note that a plethora of filters exist today. In the SAR processing domain, multilook technique was the most popular choice for reducing the speckle noise for making the data useable for application scientists. But multilook, with 4 looks improves the radiometric resolution to about 1.6dB, at the cost of degradation of the spatial resolution which becomes about 12m for the data sets used in this study. The filters studied here preserve the geometry while improving the radiometry. The quality metrics using the radiometric resolution for a homogeneous region, and the geometric resolution using a point target, is thus an optimal criteria for evaluating the performance of denoising filters, including the geometric fidelity and shape function.

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4. CONCLUSION

A number of techniques have been developed during the recent times for the speckle noise removal from SAR images. Most of these filtering techniques have been assessed in terms of radiometric quality using the ENL as reported in various papers. Apart from these a number of quality metrics for evaluating the radiometric and geometric aspects developed for calibration of SAR signal processing systems have been described in this paper. Some of the quality metrics have been used to evaluate the performances of some of the standard denoising algorithms used for filtering of SAR data. The 3dB width of the impulse response function(IRF) of Corner Reflector targets in the range and azimuth directions are found to be suitable indicators for geometric quality. Radiometric quality is defined by the radiometric resolution in a homogeneous area which is found to be a suitable metric for assessing the radiometric quality of the filtered image. From the analysis done in this study it is observed that wavelet based denoising gives better performance compared to spatial domain filters, whereby the quality metrics identified here show good results for all the aspects of the image.

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