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SAR IMAGE DE-NOISING USING ADDITIONAL FILTERS IN LPG-PCA AND GUIDED FILTER

[1]Tushar Srivastava (Author), [2]Vikas Yadav (Co-Author)

[1]M.Tech Student, [2]M.Tech Student

[1]Digital Electronics and Systems (Electronics and Communication),

[1]Kamla Nehru Institute of Technology, Sultanpur, Uttar Pradesh, India

Abstract : In this process, we propose an image de-noising algorithm using a targeted external database instead of a generic database. Here, a targeted database refers to a database that contains images relevant to the noisy image only. As will be illustrated in later parts of this process, targeted external databases could be obtained in many satellite images. Hence the satellite image de-noising is the crucial for land cover change detection and land type classification systems. This process will go to achieve both the SAR image de-noising and then SAR image classification.

***IndexTerms* - Synthetic Aperture RADAR (SAR), De-noise, Speckle Noise, Local Pixel Grouping - Principle Component Analysis, Guided Filter, Modified Directional Filter, Multi-scale Edge Preserving Decomposition, Sharpening Filter**

I. INTRODUCTION

SAR (Synthetic Aperture Radar), type of system which can take Two-dimensional pictures, or rebuild Three-dimensional landscapes. By moving the radar antenna across a target region, SAR delivers finer spatial resolution than standard stationary beam-scanning radars. SAR evolved from a more advanced version of side looking airborne radar and is frequently placed on a moving platform, such as an aero plane or a spacecraft (SLAR). SAR may detect changes in water and moisture levels, habitat effects of natural or human disturbance, and changes in the Earth's surface after natural disasters such as earthquakes and sinkhole openings through darkness, clouds, and rain.

To 'Synthesize' a very long antenna in SAR, forward motion of the actual antenna is used. A pulse is broadcast at each place, and the return echoes pass through the receiver and are recorded in echo store. Each spot on the ground has its own Doppler frequency fluctuation characteristic. Matching the Doppler frequency fluctuations and demodulating by modifying the frequency variation in the return echoes from each point on the ground are both part of SAR processing. A high-resolution image is the result of this matching filter.

1.1. A Role of Frequency and Wavelength

Optical sensors capture data in the short-wave infrared, near-infrared and visible spectrums. Longer wavelengths are used in radar sensors at the cm to m, giving them unique qualities including the capacity to see through clouds.

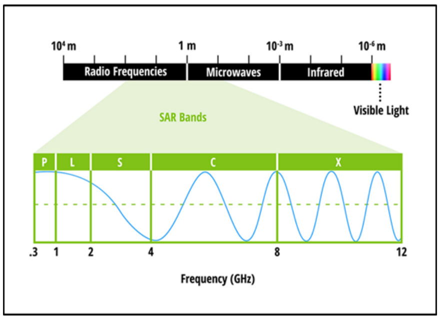


Fig 1 Electromagnetic spectrum with microwave bands inset

Wavelength affects penetration depth not only in woods, but also in other forms of land cover like dirt and ice. The WL of radar signals impacts how field interaction show and how far it cans medium penetration while working with SAR. Allowing it to penetrate deeper into a forest and interact more with huge branches and tree trunks.

1.2. Basic Principle of Synthetic Aperture RADAR

Synthetic Aperture Radar is imaging radar that is put on an instantly mobile platform. The system electronics broadcast sequential electromagnetic waves, capture echoes, then digitize and store the data for further processing. Transmission and reception take place at separate times, resulting in distinct tiny places being mapped. Digital elevation model (DEM) is employed to quantify the phase differences between complex images, calculated from different look angles to recover height information.

Different surfaces on earth, such as water, land, vegetation, or man-made structures, will exhibit different scattering properties and having different structural dimensions which mostly make difference in all patterns. SAR imaging in 4D and multi-D allows for imaging of complicated environments, such as metropolitan regions, and outperforms traditional interferometry techniques like persistent scattered interferometry (PSI).

1.3. Mechanisms of Polarization and Scattering

By adjusting the analysed polarisation in both transmit and receive lines, radar may collect signals in various polarizations. The orientation of the plane in which the transmitted electromagnetic wave oscillates is referred to as polarisation. SAR sensors normally transmit linearly polarised signals, despite the fact that the orientation might be at any angle. It's vital to remember that the quantity of signal ascribed to many scattering types varies with regard to wavelength, because wavelength affects depth of penetration in signal.

Some of the important key benefits are Remote Sensing, Material Characterization, Imaging and Microscopy, Communication and Information Security, Sensing of the Atmosphere and Astronomical Research which partially or fully related with the process of mechanism of polarization and Scattering.

1.4. Scanning Modes

The sensor operates in three different modes, Strip map SAR-mode, Spotlight SAR-mode, Scan SAR-mode with 10 km long and 10 km broad area is captured with a resolution of 1 to 2 meters, resolution of 3 to 6 meters and covers a 30-kilometer-wide strip, 100-kilometer-wide strip is acquired at a resolution of 16 meters respectively.

II. IMAGE CREATION FOR SAR

A camera that shoots images and SAR is comparable to that. Both optical and SAR cameras have different penetrating powers. This capacity to penetrate is determined by the catching phenomena. Unlike SAR, which uses radar signals it transmits, an optical camera uses light to make pictures. This significant improvement in SAR allows for picture capturing in total darkness as well as seeing through clouds, rain, fog, and snow.

2.1. Image Creation of SAR

A lot of information and processing power are needed to produce a SAR image. Although this kind of radar monitors objects only and estimate its velocity, it uses a time interval to determine the distance travelled from antenna to objects & back to the antenna. A lot of computational power and a lot of data are needed to create an image. It requires an antenna that is especially long. When aircraft is flying and moving ahead, antenna of SAR sends radio waves of high-frequency - also known as waves of radar - in direction of the field area. Antenna in center of the pulses gathers backscattered radio waves of high-frequency which reflected off of nearby ground-based objects. Additionally, it conveys information on the SAR's motion, such as whether it is moving closer to or farther away from the ground item. If the backscattered pulses are closely spaced, the SAR-equipped aircraft is getting closer to the ground; if they are widely spaced, the aircraft is moving farther away from the ground.

There are certain pulses that show a specific pattern in the massive amount of backscattered pulse data acquired; this exact pattern indicates that those pulses are reflected off from the same area. During this procedure, the precise location of the plane during the times it broadcast and received the suit the pattern pulses is known, making it easy to map the point of object on created image. Image detailing has been mapped; however the brightness of the point is unknown. The brightness of SAR is determined by the signal intensity it receives.

2.2. SAR Image Brightness and Roughness

Blackness & Brightness in SAR pictures, caused by target object's ground surface's structure. The surface's roughness affects the brightness of SAR photographs. Only a portion of the RADAR's high-frequency waves that are broadcast by the antenna and make contact with the ground are reflected back to the station. With this antenna, radar signals may be transmitted as well as received. The SAR picture clearly depicts the sections of RADAR signals that return to the antenna in sufficient quantities. The SAR pictures look black in certain areas because only a tiny portion of radar signals are backing reflected to antenna. The surface's geometry, roughness, electrical properties, and polarization direction all have an impact on the signals that are returned by radar.

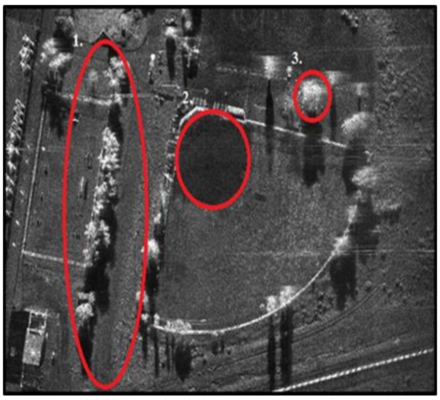


Fig 2 SAR image Areas – Bright & Dark

The radar wave's influence on the surface orientation of the target ground. In the image above, the two types of surfaces are shown. The smooth terrain's surface where a radar signal encounters it. The angle at which the radar signal is incident and the angle at which it is reflected are almost equal. This means that the radar antenna has either received no RADAR returns or very little energy. In this case, the projection appears black in the SAR picture. The most typical place for this to occur is in a river or other still body of water with reflection which is specular. The time, radar sent signal strike with a surface having rough structure with randomly & uneven orientation on surface, radiation of radar, reflected in different way.

2.3. Problems in SAR Image

There are several reasons for the SAR system's functioning to be disrupted and the quality of the SAR image to deteriorate. Nonlinearities in the SAR subsystem are one of the explanations, as they impair the system's ability to resolve. Noise is a common problem with SAR photos, and the primary source is image acquisition. Inaccuracies in the position and velocity of the sensor are additional sources of noise, and both have a geometrical impact on the SAR image.

In Geometric Distortion, major sources are space-borne or airborne platform causes distortion through variations in velocity. The rotation of earth, distortion is caused by topographic effect and curvature. In System Nonlinear Effects, major sources are the system impulse response function is degraded by amplitude and phase errors (IRF). Thermal noise reduces the system's dynamic range. In Range migration, major sources are as the object approaches the synthetic aperture, a hyperbola-shaped reflection appears. Because SAR tackles the two-dimensional space-variant problem, curvature is dependent on range compressed response. The main flaw is due to speckle noise effect in which main sources are SAR pictures are created as a result of high-frequency radar waves being continuously broadcast and interacting with targets.

This on-going interaction produces both helpful and detrimental nosiness. The quality of the SAR picture is lowered as a result of the noise spreading over the image and creating speckle noise effects. The default noise type in the SAR picture is granular pattern noise within a resolution cell, there are several elements distributed with an arbitrary distribution. When SAR pictures are captured or as a result of unchecked constructive or destructive interference, speckle noise, a granular pattern, develops. A SAR, on the other hand, sends a very accurate signal to its target, and when the reflected radiation returns, it captures not only the amplitude but also the phase.

III. PROPOSED METHOD

Image de-noising is a process that aims to remove unwanted noise from images while preserving important details and structures. One approach to image de-noising is the combination of local pixel grouping (LPG) with principal component analysis (PCA), guided filtering, and enhancement techniques like modified directional filters, multi-scale edge preserving decomposition, sharpening filters, and directional filters.

Local pixel grouping involves dividing the image into small patches and performing de-noising operations on these patches individually. PCA is a statistical technique used to transform the original pixel values into a new set of uncorrelated variables called principal components. By applying PCA to each patch, the algorithm identifies the principal components that contain the most relevant information, while discarding the components associated with noise.

3.1. SAR Image Dataset

A collection of digitized photographs used to develop computer vision models is known as an image dataset. Hundreds or thousands of photos, together with relevant captions and comments, are frequently included. The photos may be used to train and test computer vision algorithms since they are often carefully labeled by human experts. Image databases are employed in a variety of industries, including medicine, robotics, and autonomous vehicles.

Synthetic Aperture Radar (SAR) image datasets can be valuable for image de-noising tasks. SAR sensors capture images by transmitting microwave signals and measuring the backscattered signals from the Earth's surface. These images are prone to various types of noise, such as speckle noise, which can degrade the quality and interpretability of the imagery.


(a) Image 1


(b) Image 2


(c) Image 3


(d) Image 4


(e) Image 5


(f) Image 6


(g) Image 7


(h) Image 8

Fig 3 SAR Image Dataset

3.2. Flow Chart

These several methods are combined to reduce the noise in a SAR image. It's important to note that the specific implementation details may vary depending on the exact algorithm used and the specific parameters chosen.

The de-noising method using Local Pixel Grouping-PCA (Principal Component Analysis) and Guided Filter is a technique to remove noise from an image while preserving its details and structures. It combines the power of PCA for dimensionality reduction and the guided filter for edge-preserving smoothing.

Step 1: Pre-processing
Input SAR image
Step 2: Feature Extraction
Step 3: Classification
Adding noise in image
Step 4: De-noising
De-noising using LPG-PCA
Modified directional filter
De-noising using guided filter
Multi-scale edge preserving decomposition
Sharpening filter
Directional filter
Step 5: Post-processing
De-noised SAR image

3.3. Explanation of Proposed Methodology

Pre-processing is defined as before proceeding to de-noise the SAR image, pre-processing is done to create a better base for the de-noising process. In this step, we include a raw image as input image. Feature Extraction is a step which involves extracting relevant features from the SAR image such as texture, intensity, and other spectral information. Classification is a step which involves classifying the objects in the SAR image into different classes such as buildings, roads, vegetation, etc., using image segmentation and classification algorithms. To obtain useful information from a SAR picture, two crucial procedures are image segmentation and classification. In image segmentation, the image is divided into many segments, frequently depending on the characteristics of the objects in the image. For instance, it is possible to group pixels with the same color or texture. This process is crucial for identifying objects.

3.4. Enhancement in Proposed Methodology

Enhancement done in SAR image de-noising method is useful for the result -

3.1.1. Use of Multi-Scale Edge-Preserving Decomposition for de-noising SAR images

Using the Multi-Scale Edge-Preserving Decomposition (MSEPD) method, synthetic aperture radar (SAR) pictures may be made noise-free. System noise, atmospheric impacts, and other variables, among others, all have an impact on the noise in SAR photographs. MSEPD is a noise-removal technique that lowers the noise levels while maintaining the image's edges. A multi-scale method is used by MSEPD to lower the amount of noise in a picture. With this method, the picture is smoothed at several scales before the results are combined to create a single, noise-free image. A filter that protects the image's edges is used in the smoothing process. The end result is a picture with less noise but with unaltered edges. This method allows for the retention of the edges while still decreasing the noise levels, making it particularly helpful for SAR photos.

The Multi-Scale Edge-Preserving Decomposition (MED) technique is commonly used for de-noising images. It decomposes an image into multiple scales, preserving the edges while removing noise. The equation for the MED can be represented as follows:

$$I = F + N \qquad (3.1)$$

Where, I represent the noisy input image. F denotes the filtered image after de-noising. N represents the noise present in the image.

3.1.2. Applying Modified Directional Filter

The Modified Directional Filter (MDF) is an image de-noising technique that aims to reduce noise in digital images while preserving important image details. It employs a filter that operates in different directions to exploit this directional information and effectively suppress noise while preserving edges and other significant image details. Here is a brief overview of the steps involved in the MDF algorithm: Decomposition: The input image is decomposed into different scales using a multi-scale decomposition technique such as the wavelet transform. This decomposition helps capture image structures at different scales. Directional filtering: A directional filter is applied to each scale of the decomposed image. The filter responds strongly along the local orientations of the image structures while attenuating noise components that do not align with these directions. The filter can be designed based on techniques like local gradient estimation or the non-local means approach. Weighting and aggregation: The filtered images obtained from the previous step are weighted and aggregated to produce the final de-noised image. The weights are usually determined based on the noise characteristics and the local image content.

Here's the formula for the Modified Directional Filter, Let's denote the de-noised output image from LPG-PCA as D (i, j), where (i, j) represents the pixel coordinates.

$$MDF(i, j) = D(i, j) + \alpha \times (D(i, j) - F(i, j)) \qquad (3.2)$$

In this formula, α is a weighting parameter that controls the strength of the directional filtering, and F (i, j) represents the directional information obtained from the LP-PCA algorithm. The term (D (i, j) - F (i, j)) represents the difference between the de-noised pixel value and the corresponding directional information at that pixel.

3.1.3. Applying directional filters to remove noise

One method for reducing the amount of noise in an image is to employ directional filters to eliminate speckle noise. Medical imaging, including ultrasound and X-ray images, frequently contain speckle noise. Numerous things, like the movement of the instrument, the radiation's intensity, or the interference of multiple waves, might contribute to this noise. The basic idea behind employing directional filters to reduce speckle noise is to separate the image into smaller blocks and apply a directional filter to each individual block.

By identifying patterns in the image and then applying a filter to each pattern, the directional filter finds patterns in the image. By eliminating the signal's high frequency components, the filter is intended to lessen the speckle noise that exists in the picture. This improves representation of the underlying image and lowers the amount of noise in the image.

The equation for a directional filter used to remove speckle noise from an image can be represented as follows:

$$FI = Image - (Image * Directional\ Kernel) \qquad (3.3)$$

In this equation, FI is Filtered Image and the "Image" refers to the input image that contains speckle noise. The "Directional Kernel" represents a filter mask or convolution kernel specifically designed to capture directional features of the speckle noise. The "*" operator denotes convolution.

The Directional Kernel is typically designed to emphasize or enhance dominant direction of the speckle noise. One common choice is a kernel that resembles a line or edge filter aligned with the predominant direction of the speckle artifacts. The kernel can be manually designed or learned from training data. By convolving original image with the Directional Kernel, the filter enhances dominant directional features associated with the speckle noise. Subtracting this result from original image effectively suppresses the speckle noise while preserving other image details.

3.1.4. Use Sharpening Filter

A sharpening filter is used to enhance the edges of an image, making them appear stronger and more defined by increasing the contrast between adjacent pixels. This is often used to make photos look more vibrant and detailed. Sharpening filters can be applied to both digital and film photographs and can be used to fix images that have been soft due to poor lighting or camera settings. They can also be used to adjust levels of clarity and focus on specific areas of an image.

The sharpening filter is typically implemented using a convolution operation with kernel that enhances high-frequency components of an image. One common sharpening kernel is the Laplacian filter.

Here's the equation for applying a sharpening filter to an image: Let I(x, y) be the original image and S(x, y) be the sharpened image –

$$S(x,y) = I(x,y) + K \times (I(x,y) - B(x,y)) \qquad (3.4)$$

In this equation, (x, y) represents the pixel coordinates in the image. I(x, y) is the intensity value of the original image at pixel (x, y). S(x, y) is the intensity value of the sharpened image at pixel (x, y). B(x, y) is the blurred version of the original image at pixel (x, y), typically obtained using a low-pass filter. K is a parameter that controls the strength of the sharpening effect. Higher values of k result in a stronger sharpening effect.

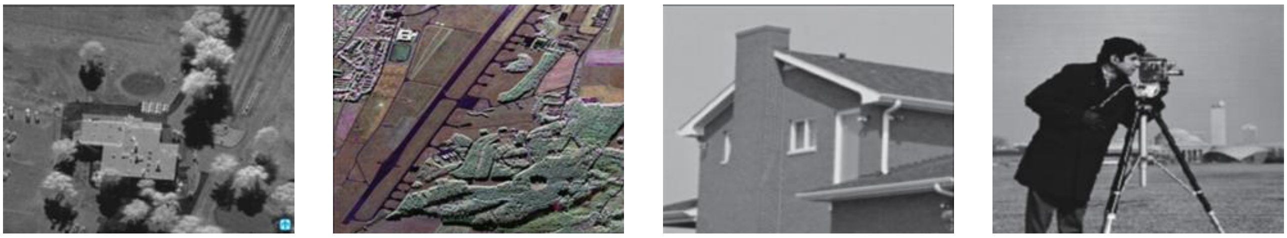
Note that the equation assumes grey-scale images. For color images, the sharpening filter can be applied separately to each color channel (e.g., red, green, and blue) or by converting the image to a different color space (e.g., YUV or LAB) and applying the filter to the appropriate channel. It's worth mentioning that there are various other sharpening filters, such as the un-sharp mask and the high-pass filter, which use different equations or kernel designs. The specific choice of sharpening filter depends on the desired effect and the characteristics of the image.

There are many different ways to improve SSIM and PSNR Value in this proposed method, Increase the number of components used in algorithms. This will ensure that more of the noise is removed from the SAR image. Increase the strength of the regularization of the LPG-PCA and Guided Filter algorithms. This will help to reduce the noise and improve the quality of the de-noised SAR image. Experiment with different parameters of the algorithms. This will help to find the optimum parameters that result in the highest quality of de-noising. Adjust the size of the patches used in the algorithms. Smaller patches will help to reduce noise more effectively. Increase the number of iterations of the algorithms. This will help to further reduce the noise and improve the quality of the de-noised SAR image.

IV. RESULT

The outcomes of the suggested approach for de-noising SAR photos can be quite good, lowering noise levels and improving overall image quality. This can assist increase accuracy & resolution of photographs, which can be helpful for applications like mapping and geospatial analysis. Additionally, because less noise is present in the pictures, this technique can speed up and lower the process time of post-processing and analysis.

In SAR images, white, dark and grey areas represent different characteristics of the observed scene: White areas are these regions in SAR images typically indicate high backscatter or strong radar reflections. Dark areas regions in SAR images suggest low backscatter or weak radar reflections. Grey areas in SAR images represent moderate backscatter or intermediate radar reflections. These regions exhibit a mix of strong and weak radar reflections.



(a) Image 1 (b) Image 2 (c) Image 3 (d) Image 4

(a) Image 1 (b) Image 2 (c) Image 3 (d) Image 4

Fig 4 SAR De-noised Output Images

ENL is a standard parameter widely used in the remote sensing. It can measure the ability to suppress the noise in homogeneous areas. Larger ENLs values indicate stronger speckle suppression and an improved ability to distinguish different grey levels. Proposed method has excellent ENLs in homogeneous areas. L is the ENL.

Table 1 PSNR Values of Dataset Images (in dB)

Dataset	L=1	L=2	L=4	L=16
Image 2	26.39	26.97	28.56	29.68
Image 3	28.61	31.22	34.89	35.07
Image 4	30.02	31.79	35.92	36.26
Image 5	27.30	28.12	29.72	31.56
Image 6	28.42	29.43	31.68	35.21
Image 7	29.17	30.51	32.74	34.87
Image 8	28.54	29.72	31.01	33.64

Table 2 SSIM Values of Dataset Images

Images	L=1	L=2	L=4	L=16
Image 2	0.7980	0.7245	0.8112	0.9092
Image 3	0.8087	0.9021	0.9123	0.9782
Image 4	0.8297	0.8842	0.9348	0.9816
Image 5	0.8115	0.9238	0.9626	0.9924
Image 6	0.8678	0.8906	0.9527	0.9899
Image 7	0.8243	0.8731	0.9581	0.9834
Image 8	0.8474	0.8941	0.9312	0.9782

4.1. Result Comparison with other methods

Start by presenting the evaluation metrics used to assess the performance of the de-noising methods, such as peak signal-to-noise ratio (PSNR), structural similarity index (SSIM), or mean square error (MSE). Highlight the values obtained by the previous methods and your proposed method for a fair comparison. It employs a weighted averaging technique to remove noise by considering similarities between image patches. FANS take advantage of the redundancy present in natural images and effectively reduce noise while preserving fine details. The ANL method is based on the finding that patches in SAR pictures frequently display comparable characteristics.

By looking for comparable patches in the image and averaging them together to minimize noise, FANS takes use of this phenomenon. LPG-PCA is an image de-noising algorithm that utilizes principal component analysis (PCA) technique. It applies PCA on overlapping image patches to capture the local image statistics and then adaptively combines the resulting principal components to reconstruct the image.

(a) PM (b) Frost (c) H-LSSC (d) FANS

Fig. 5 Image 1 de-noised comparison with other de-noising methods

It applies PCA on overlapping image patches to capture the local image statistics and then adaptively combines the resulting principal components to reconstruct the image.

Table 3 PSNR Value Comparison of Image 1 (in dB)

Methods	**L=1**	**L=2**	**L=4**	**L=16**
Noisy	11.67	14.45	17.31	23.24
Frost	17.22	20.42	24.32	27.45
H-LSSC	20.21	23.34	25.87	29.12
LPG-PCA	25.29	27.19	27.67	30.44
FANS	27.87	28.28	30.19	31.97
LPG-PCA & GF	28.33	29.97	31.72	32.43
PM	29.92	31.63	34.22	34.85

Table 4 SSIM Value Comparison of Image 1

Methods	**L=1**	**L=2**	**L=4**	**L=16**
Noisy	0.7782	0.7867	0.8281	0.8901
Frost	0.7897	0.7902	0.8367	0.8982
H-LSSC	0.7899	0.7922	0.8713	0.9176
LPG-PCA	0.7921	0.8216	0.8801	0.9356
FANS	0.8112	0.8603	0.9023	0.9487
LPG-PCA & GF	0.8172	0.8770	0.9123	0.9622
PM	0.8202	0.8897	0.9424	0.9719

V. CONCLUSION & FUTURE WORK

The combination of Local pixel Grouping-PCA with guided filter, Multi-scale edge-preserving decomposition, Modified directional filter, sharpening filter, and Directional filter can potentially improve the de-noising performance of SAR images. By leveraging these techniques, it is possible to enhance the quality of SAR images by reducing noise and preserving important features.

Future work will be done as Performance Evaluation in which it conduct a thorough evaluation of the proposed de-noising method using quantitative metrics such as peak signal-to-noise ratio (PSNR), structural similarity index (SSIM), and visual inspection. Compare the results with existing state-of-the-art de-noising techniques to determine the effectiveness and superiority of the proposed method. Parameter optimization which investigate the optimal parameter settings for each de-noising component in the proposed method. Fine-tuning these parameters can lead to further improvements in de-noising performance and image quality. Robustness Analysis which assess the robustness of the proposed method against different types of noise commonly encountered in SAR images, such as speckle noise, impulse noise, and Gaussian noise. Evaluate its performance across a wide range of noise levels to determine its applicability in real-world scenarios. Computational Efficiency in which we explore strategies to optimize the computational efficiency of the proposed method.

SAR image de-noising often involves processing large volumes of data, so finding ways to reduce computational complexity can significantly enhance the practicality and applicability of the method. Generalization is like test in which proposed method on a diverse set of SAR images acquired from different imaging platforms, frequencies, and environmental conditions. Assess its ability to generalize and produce consistent de-noising results across various datasets.

By addressing these aspects, future research can further refine the proposed de-noising technique, expanding its applicability and improving its overall performance in SAR image de-noising tasks.

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