DOI : https://doi.org/10.56452/7-5-203

ISSN: 0974-5823 Vol. 7 No. 5 May, 2022

International Journal of Mechanical Engineering

An overarching scheme for developing algorithms for analyzing coherent polarimetric pictures

Priya Kohli

Asst. Professor, School of Computing, Graphic Era Hill University,

Dehradun, Uttarakhand India 248002

Abstract: Hydrology, agriculture, oceanography, forestry, catastrophe monitoring, and military surveillance are just few of the fields that have benefited greatly from satellite-based earth observation data. Advanced artificial aperture radar based imagery has led to explosive development in satellite-based applications during the last three decades. Users are more used to optical pictures, but the all-weather, day-and-night imaging capacity of spacecraft was launched-based SAR images has led to a dramatic increase in their acceptability and utilisation. Polarimetric SAR expanded the benefits of SAR by allowing for more precise feature extraction from targets via the use of polarisation diversity in images. Polarimetric SAR use numerous polarisations to identify targets, as opposed to only one for traditional SAR. Since PolSAR uses a coherent imaging mechanism, it suffers from the same problem of multiplicative speckle noise as SAR does. To make the most of the PolSAR pictures for remote sensing applications, despeckling is a crucial first step in the processing pipeline. Since spatial domain filtering degrades the retrieved image through over smoothing and removal of image fine details, the first part of the research focused on constructing a transform domain filtering approach for polarimetric satellite imagery using bandelet transform. The covariance matrix components are multiplicatively modelled as speckle noise using a Wishart distribution and bandelet coefficient thresholding. As the best threshold selection strategy, the GCV thresholding approach is used. Real polarimetric pictures obtained by a number of airborne and space borne PolSAR systems, as well as Montecarlo simulation-generated examples, are used to verify the accuracy of the proposed approach. Results from a quantitative analysis using a variety of performance criteria; a qualitative analysis of the actual PolSAR system

Keywords: Polarimetric, thresholding, PolSAR, bandelet transform

Introduction

The use of satellites for remote sensing has advanced greatly in recent decades. There has been a growing tide of recognition and usage of satellite-derived Synthetic Aperture Radar (SAR) data over the last couple of decades, despite the fact that people are still overwhelmingly familiar with optical imagery. The increased availability of commercial SAR satellite information as well as the development of more sophisticated processing and analysis tools have contributed to this trend. SAR based imaging has the distinct benefit of being able to acquire a target region reliably regardless of the weather or lighting conditions

[1]. When data are handled and analysed adequately, SAR's true advantages become apparent. The resulting picture from SAR data has several useful qualities that may be used for more than just visual analysis. Polarimetry is a significant addition to SAR that improves target feature extraction [2, 3]. Unlike traditional SAR Polarimetric SAR (PolSAR) takes readings of the objects at a variety of angles and frequencies. The resulting high-dimensional data may be used to distinguish between different types of scattering to help identify individual scatterers. For geoscientific and related applications, understanding the polarisation of the backscattered wave is crucial since it provides insight into the scatterer's geometrical structure, direction, and other geophysical aspects. [4] With the extra data it offers on the target object's shape, introductions, and dielectric characteristics, PolSAR imaging has several potential uses. Multiplicative speckle noise is produced by the coherent imaging method used in PolSAR and has a major impact on data quality [5, 6]. Therefore, segmentation and classification are not possible without first performing speckle reduction as a pre-processing step in PolSAR. Speckle in PolSAR photos may be removed during or after the imaging process. The first approach uses an incoherent tasking-look average during image processing to improve the SAR picture by averaging together uncorrelated photos from the no overlapping spectrum, at the cost of reduced spatial resolution. Spatial filtering and transform-based filtering are examples of the later techniques. Several strategies, such as spatial filtering schemes and classical filtering methods, are being proposed for PolSAR speckle suppression. Boxcar, the Refined Lee filter, the Scattering prototype-based filter, the intensity-driven Driven Adaptive Neighbourhood (IDAN) filter, etc. are all examples of traditional approaches that are quick and easy to implement [7]-[9]. In order to carry out the filtering process and calculate the noise dispersion of the noisy picture, most of these methods use window-based filters. While these methods significantly reduce speckle in homogeneous regions and have low computational complexity, they blur heterogeneous regions of the image due to losses in its mathematical features. By searching and comparing not only the values at a single point in a tiny local window, but also the geometrical characteristics in the full picture, Non Local Means (NLM) filtering approaches outperform conventional techniques [10, 11]. In this case, the computational cost may be minimised by choosing the bigger window, but the artefacts caused by local averaging must be accepted. In order to effectively remove speckle noise [12], variational techniques use a global regularisation as opposed to the classic methods' filtering approach focused on processing the picture pixels one by one. When it comes to cleaning up single-channel SAR data from Gaussian noise, the despeckling methods based on Partial Differential Equations (PDEs) have shown to be very successful.

Despite efforts to use PDE-based algorithms to eliminate speckle in PolSAR pictures, this approach is not optimal because of the complicated Wishart distribution of PolSAR data, which includes complex values in the covariance matrix [13]. The sparse representation and straightforward filtering via thresholding of the transform coefficients [14], [15] have also contributed to the rise in popularity of transform-based PolSAR speckle filtering approaches. Applying an appropriate threshold value to the transform coefficients is what makes transform-based filtering so successful in eliminating unwanted noise. Over the past decade, researchers have proposed a plethora of different transform-based methods. These transformations are sometimes referred to collectively as x-lets [16, 17] and comprise not only curvelets and contourlets but also smoothlets, directionlets, bandelets, and others. Since the basis functions of the curvelet and contourlet transforms sparsely represent image singularities, these schemes provide efficient despeckling performance. Subsampling techniques used in these transforms' processing, however, would have a detrimental impact on despeckling efficiency [18]. These methods were also less desirable since their calculations were more difficult than schemes based on the independent 2D wavelet transform. The transform domain filter is suggested in the POSSC technique, which is based on the patch order technique and simultaneous sparse coding. [19], [20].

It has a high computational complexity but excellent despeckling performance. Due to their limited directional features, most of the aforementioned methods are unable to truly extract or retain the finer details of the target. The bandelet transform stands out among directional transforms because of its ability to preserve geometric details. Speckle noise is an inevitable part of PolSAR photos. Despeckling algorithms that are both efficient and accurate must be used as a pre-processing step before any useful information can be extracted from these pictures. It is important that the despeckling method not degrade the image's geometrical properties while still being successful in both homogeneous and diverse regions. In this context, geometric transformations like the bandelet transform may be quite helpful. In recent years, the bandelet transform has been widely used as a critically sampled, completely reconstructible, anisotropic basis function for picture representation. The inherent geometrical structures in photos may be captured by using bandelets, a multiscale and multidimensional signal analysis technique. The bandelet transform [[23], [24]] uses the geometric flow to create orthogonal bandelet bases from sharp transitions in pictures. Other transformations, such as the wavelet, cosine, and Fourier transforms, etc., fail to adequately represent the geometric regularity of visual structures. A bandelet may be constructed from a geometric flow of vectors if the grayscale values of the picture vary regularly with the local directions. A vector's geometric flow represents the regularity with which it travels along the image's edges. While linear geometric flow is favoured, it is not the only type of flow that occurs in images with varying degrees of grey. Bandelet bases in picture despeckling applications need optimisation of this geometric movement. Using bandeletization of warped wavelet bases, which capitalises on picture regularity and geometric flow, bandelet bases may be created.

This motivated the creation of bandelet transform–based despeckling algorithms. Choosing a good estimate for the threshold is crucial to the success of threshold-based despeckling methods. The best threshold may be calculated using a number of different strategies. Several of these methods rely on knowing the noise variance in advance to find the best threshold. In many practical contexts, this may not be easily accessible. The threshold estimate based on the Generalised Cross Validation method gets over this shortcoming [25]. This motivates the research and development of GCV threshold-based despeckling algorithms in the bandelet sector. Using both qualitative and quantitative metrics, we demonstrate the efficacy of bandelet-based despeckling, and we go on to show how enhancing the despeckling performance by creating an efficient edge detection approach based on the bandelet scheme is possible. The computational cost of bandelet processing may be reduced by using a geographically adaptive processing assisted by directional variance [26]. Here, directional variance is initially calculated to identify disparate picture characteristics. Traditional wavelet is used in cases when the directional characteristics in the target pictures are not very salient. Since most PolSAR despeckling filters are founded on the exponential speckle noise model, we further refine the bandelet based method with the additives multiplicative model to make the most of the polarimetry benefits of these images. Here, the polarimetric properties are maintained while processing the covariance matrix in a way that distinguishes between diagonal and off-diagonal members.

Literature Review

Pu Xia et.al.,(2021) Polarimetric dehazing techniques are quite effective in rescuing haze-damaged photos. However, dehazing causes noise and colour distortion, and those techniques can't recover distant targets. Light having a longer wavelength, particularly in the infrared band, suffers less attenuation from haze, as we found in a prior research. To take advantage of this feature, we dissect the dehazing procedure into 16 distinct spectral bands. To improve dehazing efficacy in short-wavelength channels, an infrared band is introduced, which both expands the visible spectrum and restores accurate colour. picture fusion of the dehazed bands is used to rebuild the original picture. Dehazed photos had more resolution and less noise, according to experimental assessments. In particular, our approach is effective in rescuing colour information from haze-affected photographs. At least 71% of blueshift can be mitigated.

Xiaofang Xu et.al.,(2021) In object-based image analysis (OBIA), where the image object itself serves as the processing unit, segmentation has shown to be an essential step. OBIA places a premium on the spatial scale used in picture segmentation. Polarimetric synthetic aperture radar (PolSAR) pictures have a high heterogeneity and a huge dynamic range, making it challenging to choose appropriate spatial scales. In this letter, we present a spatial scale selection approach for PolSAR image segmentation using polarimetric semivariograms. By using both polarimetric and statistical analysis on PolSAR pictures, the ideal spatial bandwidth value in the mean-shift technique may be calculated beforehand. The efficacy of the suggested technique in selecting the optimum spatial bandwidth for segmenting PolSAR images is confirmed via the use of a quantitative assessment of the segmentation result. The suggested adaptive optimum bandwidth selection technique for PolSAR pictures is validated by experiments on the EMISAR and UAVSAR L-band PolSAR data sets.

Maryam Imani et.al.,(2021) In this paper, we provide a method for classifying PolSAR (polarimetric synthetic aperture radar) images. The suggested technique, named ridge deviance-based polarimetric-spatial (RRPS) feature extraction, creates polarimetric-spatial features with little overlapping and redundant data. This is accomplished by fitting a ridge regression model to the outermost PolSAR polarimetric-spatial channels. The projection matrix used for dimensionality reduction is built using the regression model's weights. Using limited training sets, the suggested RRPS approach with a closed form solution achieves excellent results in PolSAR image classification.

Ruinan Wang et.al.,(2020) Under-sampling occurs in pictures of varying polarisation directions captured by a division-of-focal-plane (DoFP) imaging system. This study provides a learning approach based on sparse representation to optimise the interpolation result of DoFP pictures, hence resolving the demosaicing issue of DoFP imaging. In order to adaptively learn a sub-dictionary from each class, we first choose picture blocks rich in edge or texture information depending on the local gradient. To reduce coding mistakes, the model takes into account local similarity and the sparsity of coding coefficients as regularisation factors, and the method alternates between optimising the dictionary atoms and the coding coefficients. The experiment compares the extrapolation results of the suggested approach to those of other approaches, using a set of 8 created DoFP pictures as a reference. The suggested approach consistently achieves lower interpolation error compared to competing methods across all experimental images.

Filippo Biondi et.al.,(2020) In this letter, we create a unique unsupervised architecture for identifying the prevailing polarisation in polarimetric SAR pictures automatically. In order to achieve this, we draw on the work done in [1] and appropriately use its principles to construct a decision logic that can identify the main scattering mechanism that defines the test pixel. Our method involves combining the raw data into three sets of scaled-down vectors, which are then fed into a dominant eigenvalues classifier in accordance with the model order selection criteria. The results from the latter set of categorization methods are then used to infer the prevalent polarisation according to certain established criteria. Measured data are analysed to demonstrate the efficacy of the proposed classification architecture, and it is shown that knowledge of the dominant polarisation can be indicative of the structure type that gives rise to the dominant backscattering mechanism.

Spatially adaptive despeckling scheme for polarimetric SAR image

We describe a novel method for despeckling utilising an optimised bandelet transform based on directional variance, since the computational cost of bandelet transform-based methods is considerable in comparison to state-of-the-art methods. Applying a bandelet transform to the whole picture takes a lot of functional processing time. Therefore, directional features of images are first derived along these established axes. The bandelet transform and generalised contrast variation (GCV) thresholding are used if there are dominating directions in picture segments, whereas the wavelet transform and soft thresholding are used to reduce processing time if the region is homogenous. When compared to other methods using real PolSAR images from the ground, in the air, and in space, the proposed method is both more effective and computationally affordable.

Despeckling based on additive multiplicative speckle model

Over the past two decades, the multiplicative speckle noise model has formed the basis for most proposed speckle filtering methods. An additive-multiplicative noise model is introduced to make the most of the benefits of these pictures' polarimetry. In addition, the benefits of transform domain filtering are exploited using bandelet-based GCV thresholding. Here, we maximise gains by treating diagonal and off-diagonal covariance matrix entries differently. Using polarimetric pictures captured from aircraft and satellites, the suggested filtering approach is tested and compared to cutting-edge methods. The suggested approach shows promise in reducing the speckle content while preserving the pictures' geometrical qualities, as seen by the results.

Edge Detection in Polarimetric SAR Image

Since SAR-based natural imaging does not rely on direct sunlight, it has found widespread application in the field of remote sensing. When it comes to extracting features from natural photos, the polarimetric SAR method performs better than the standard SAR method. Polarimetric synthetic aperture radar (SAR) data has been put to good use in a variety of remote sensing fields, including hydrology, agriculture, oceanography, forestry, disaster monitoring, and even the military. PolSAR is used in both civilian and military settings to extract characteristics from a target picture. Despite its widespread usage for strategic applications, edge recognition in PolSAR pictures is a particularly difficult problem owing to the presence of speckle noise in these images. Image segmentation, feature recognition (such as highways, coastlines, crop area, forest cover, and so on), and other synthetic aperture radar applications all rely heavily on accurate edge detection. However, polarimetric SAR images have a problem with speckle noise that causes a high false alarm rate when used for edge detection. Over time, various edge detection schemes for PolSAR have been proposed. Traditional edge detectors often use sliding window approaches based on the ratio of the averages. However, because they are sensitive to the window size chosen, these detectors are not noise-proof despite their ease of implementation. In spite of these challenges, multiscale analytic techniques have been created for edge identification [66], [67]. However, there has been a lack of investigation into fully polarimetric SAR images. When compared to a single-channel SAR, PolSAR may be more effective at detecting edges.

When it comes to PolSAR pictures, most edge identification methods rely on either the Wishart likelihood-ratio test (Wishart-LRT) or Roy's greatest eigen value approach. There is a cost/benefit tradeoff between precise edge detection and noise reduction when working with windows. More and more methods based on transforms are widely used nowadays. The curvelet transform was developed as a technique for detecting lines at two different scales. In, a multiscale edge detection approach using the nonsubsampled contourlet transform (NSCT) was suggested, while in, the bandelet transform was used for object identification in the spatial domain. In, we propose an improved edge detector that makes use of a span-driven adaptive window. It's an adaptive spatial method that works well in a variety of environments. When compared to conventional methods, these approaches could efficiently detect edges in PolSAR images. In this section, we introduce a bandelet-based multiscale edge detector. Each component of the covariance matrix undergoes a series of edge enhancements in the bandelet domain before being combined to form the final edge picture. In this section, we introduce the bandelet transform as a multi-resolution edge detection approach for PolSAR pictures. pictures, especially SAR pictures, may benefit from the bandelet transform's multiscale and directional decomposition options. Decomposing the input picture using a bandelet transform allows for edge enhancement by modifying the bandelet coefficients through Lagrangian techniques to maximise the polarimetric contrast between the neighbouring subbands. In order to effectively remove speckle noise from SAR pictures without losing important geometrical elements like edges and boundaries, an algorithm is devised that takes use of the directional properties of the bandelet transform. Here, the bandelet domain is used to improve the pictures' geometrical details by merging the many scale-dependent directional subband coefficients. Both simulated and acquired PolSAR pictures are used to validate the method's efficacy. As a consequence, the recovered edges are both continuous and comprehensive, demonstrating the effectiveness of the suggested approach in reducing speckle noise.

Edge Detection Using Bandelet Transform

Although edge detection in PolSAR images is widely used for strategic applications, it is a very challenging task. Simply put, the goal of PolSAR edge detection is to identify the dividing lines between areas that have certain polarimetric and geometrical properties. This function is notoriously challenging for PolSAR pictures owing to the predominance of speckle noise, in contrast to the identification of edge features in optically sensed images. As a result, we should expect very nuanced and specific analysis of edge characteristics in PolSAR photos. A novel technique for edge enhancement and identification of PolSAR pictures in the transform domain is developed, and it is inspired by the bandelet transform's ability to retain geometric features. Before implementing the edge enhancement and detection technique, the bandelet transform is employed to successfully despeckle the PolSAR picture. By comparing these values to their maximum, we may determine their absolute worth. Edge intense region at each scale is identified in the same way as with the wavelet transform: by locating the modulus maxima of all the multidirectional subband bandelet coefficients. The edge direction corresponds to the subband's maximum modulus direction. The maximum values in each subband are then combined using pointwise multiplication, such that the final output for each pixel is the product of the highest possible value at each scale. Both the fine-scale and the coarse-scale images can identify stable edges, but the latter has a lower rate of false alerts and can collect richer edge features and more precise edge positions. Multiple scales have the potential to preserve genuine edges while simultaneously decreasing false positives.

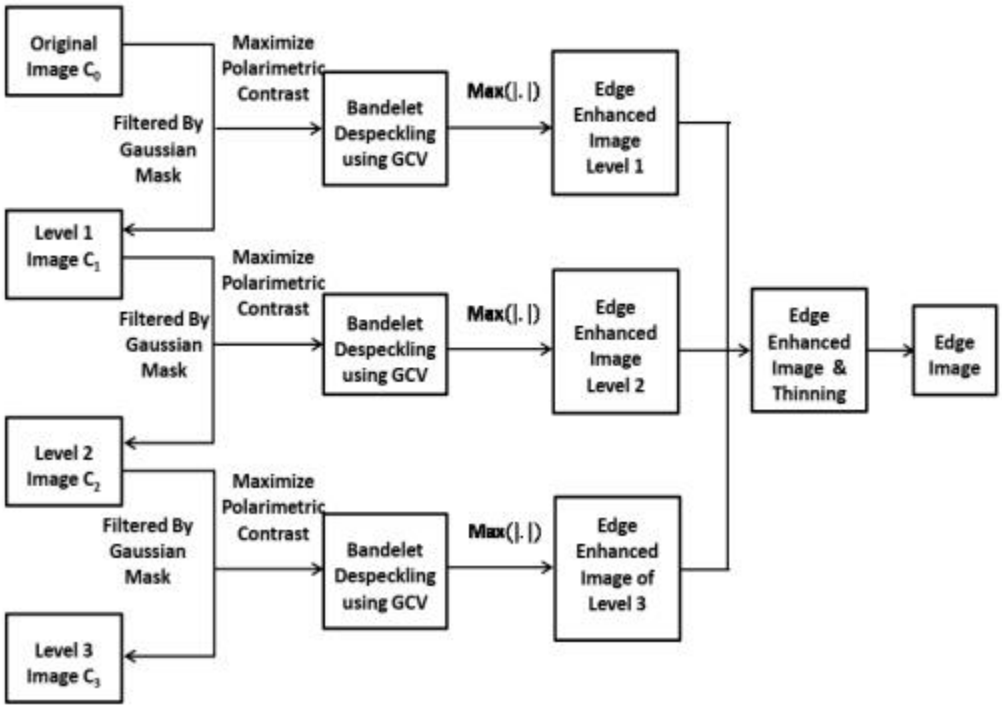

Figure.1. Block schematic of the bandelet based edge detection method

Figure 1 is a block diagram depicting the suggested procedure. As an input to the method, we have C0, which is the initial PolSAR picture created using the covariance matrix components. After being filtered using a Gaussian mask, its low-level pictures (levels 1, 2, and 3) are denoted by the letters C1, C2, and C3, accordingly.

Results with simulated images

The Monte Carlo-based method uses the complicated Wishart distribution to create single-look simulated PolSAR pictures. Both a smooth-edged and a rough-edged picture were made. Lee's greatest eigen value and the CFAR based approach are two examples of conventional edge detection techniques that use a sliding window. A large window size helps to reduce the number of false positives. However, this often leads to false positives along the actual edges and thicker edges overall. If the window size is reduced, however, false alarms due to speckle noise will increase. The windowing technique creates several false positives, which seem like points, and the edges are not continuous. In the suggested strategy, the use of the Gaussian mask helps to mitigate issues like false alarms. As can be seen in Figure 2 (f) and Figure 2 (f), this causes fewer point-like false detections and more continuous edges in the bandelet method's edge detection result. Figures 4.2 (a) and 4.3 (a) show the PolSAR Pauli RGB images of the simulated image 1 with regular edges and the simulated image 2 with irregular edges, respectively. Figures 2 (b) and 2 (b) show the corresponding despeckled images using 3 level Gaussian masking and bandelet transform. Edge-intensive pictures generated using the CFAR approach, the LFD method, and the NSCT method are shown in Figures 2 (c), (d), and (f), and 3 (c), (d), and (f), respectively, for simulated images 1 and 2. Region A from the first simulated picture and Region B from the second are used for a more in-depth examination of the edge detection capabilities. Closer examination of the photos reveals that the CFAR approach and the LFD method are both capable of detecting the edges coarsely; however, they both suffer from some degree of false detection. Edges are also overlooked in

DOI : https://doi.org/10.56452/7-5-203

cases where there is excessive speckle or if the picture edges are not well defined. The NSCT technique performs better, but still isn't able to dependably identify entire and continuous edges.

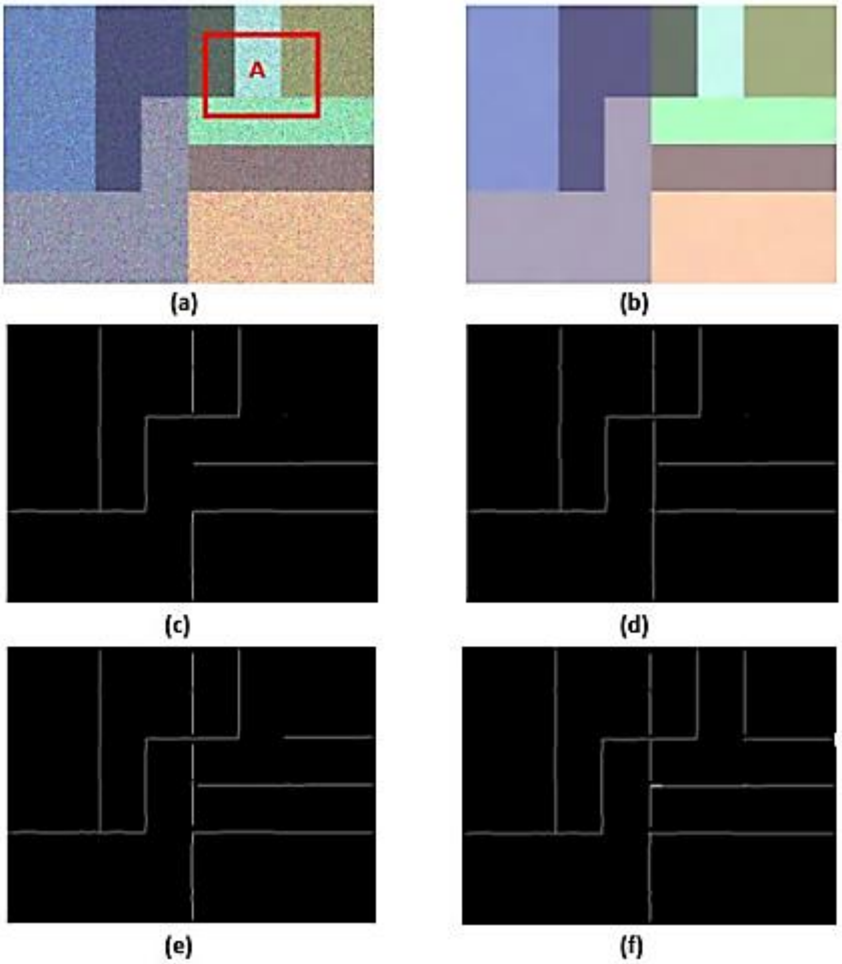

Fig. 2 (a) Pauli RGB image of Simulated image 1 (b) despeckled image, edge images using (c)

CFAR (d) LFD (e) NSCT (f) Bandelet method

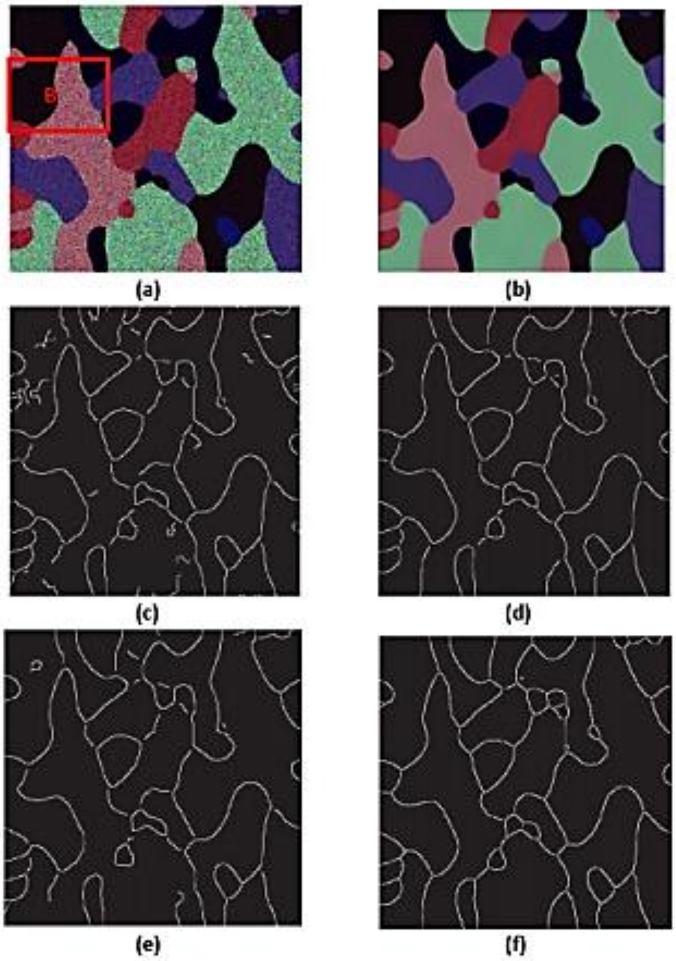

Fig. 3 (a) Pauli RGB image of Simulated image 2 (b) despeckled image, edge images using (c) CFAR (d) LFD (e) NSCT (f) Bandelet method

Conclusion

In this chapter, the bandelet transform is introduced as a unique approach to edge identification in Polarimetric SAR images. Bandelet transform is used to identify edges at many subbands and depths to provide reliable estimate of edge attributes and prevent false detection. The GCV threshold is the best one to use for despeckling since it efficiently removes the speckle noise. The algorithm's performance in terms of subjective aesthetics and edge detail preservation is validated using both simulated and actual PolSAR pictures.

References

1. P. Xia, X. Chen and X. Gao, "Polarimetric dehazing utilizing Vis-NIR spectral image fusion," *2021 International Conference on Intelligent Computing, Automation and Systems (ICICAS)*, Chongqing, China, 2021, pp. 48-54, doi: 10.1109/ICICAS53977.2021.00017.
2. X. Xu, B. Zou and L. Zhang, "Polarimetric Semivariogram-Based Spatial Scale Selection for PolSAR Image Segmentation With Mean-Shift Algorithm," in *IEEE Geoscience and Remote Sensing Letters*, vol. 18, no. 7, pp. 1239-1243, July 2021, doi: 10.1109/LGRS.2020.2994209.

3. M. Imani, "Polarimetric SAR Classification Using Ridge Regression-Based Polarimetric-Spatial Feature Extraction," *2021 26th International Computer Conference, Computer Society of Iran (CSICC)*, Tehran, Iran, 2021, pp. 1-5, doi: 10.1109/CSICC52343.2021.9420603.
4. R. Wang, W. Gao, F. Wang and C. Shen, "Non-Local Sparse Representation Method for Demosaicing of Single DoFP Polarimetric Image," *2020 12th International Conference on Communication Software and Networks (ICCSN)*, Chongqing, China, 2020, pp. 259-263, doi: 10.1109/ICCSN49894.2020.9139054
5. M. Ahishali, S. Kiranyaz, T. Ince and M. Gabbouj, "Multifrequency Polsar Image Classification Using Dual-Band 1D Convolutional Neural Networks," 2020 Mediterranean and Middle-East Geoscience and Remote Sensing Symposium (M2GARSS), Tunis, Tunisia, 2020, pp. 73-76, doi: 10.1109/M2GARSS47143.2020.9105312.
6. F. Biondi, C. Clemente and D. Orlando, "An Eigenvalue-Based Approach for Structure Classification in Polarimetric SAR Images," in *IEEE Geoscience and Remote Sensing Letters*, vol. 17, no. 6, pp. 1003-1007, June 2020, doi: 10.1109/LGRS.2019.2940420.
7. X. Tu et al., "Division of focal plane red – green – blue full-Stokes imaging polarimeter", Applied Optics, vol. 59, no. 22, pp. G33-G40, May 2020.
8. L. Pallotta and D. Orlando, "Polarimetric Covariance Eigenvalues Classification in SAR Images," in *IEEE Geoscience and Remote Sensing Letters*, vol. 16, no. 5, pp. 746-750, May 2019, doi: 10.1109/LGRS.2018.2881485.
9. T. Jiang et al., "Minimized Laplacian residual interpolation for DoFP polarization image demosaicking", Applied Optics, vol. 58, no. 27, pp. 7367, September 2019.
10. S. Wen, Y. Zheng, F. Lu and Q. Zhao, "Convolutional demosaicing network for joint chromatic and polarimetric imagery", Optics Letters, vol. 44, no. 22, pp. 5646-5649, November 2019
11. A. Tombak, İ. Türkmenli, E. Aptoula and K. Kayabol, "Pixel-Based Classification of SAR Images Using Feature Attribute Profiles," in *IEEE Geoscience and Remote Sensing Letters*, vol. 16, no. 4, pp. 564-567, April 2019, doi: 10.1109/LGRS.2018.2879880.
12. P. Xia and X. B. Liu, "Study on the polarization spectral image dehazing", Spectrosc. Spect. Anal., vol. 37, pp. 2331-2338, 2017.
13. H. Maurya and R. K. Panigrahi, "PolSAR image classification using generalized scattering models," 2017 Progress in Electromagnetics Research Symposium - Fall (PIERS - FALL), Singapore, 2017, pp. 408-412, doi: 10.1109/PIERS-FALL.2017.8293172.
14. A. Masjedi, M. J. Valadan Zoej and Y. Maghsoudi, "Classification of Polarimetric SAR Images Based on Modeling Contextual Information and Using Texture Features," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 54, no. 2, pp. 932-943, Feb. 2016, doi: 10.1109/TGRS.2015.2469691.
15. J. B. Wang, N. He, L. L. Zhang and K. Lu, "Single image dehazing with a physical model and dark channel prior", Neurocomputing, vol. 149, pp. 718-728, 2015.
16. L. Zhang, L. Sun and W. M. Moon, "Polarimetric SAR image classification based on contextual sparse representation," *2015 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, Milan, Italy, 2015, pp. 1837-1840, doi: 10.1109/IGARSS.2015.7326149.