POLARIMETRIC SAR IMAGE DENOISING USING THE IMPROVED IMMSE FILTER

Mohamed Yahia (1,2), Tarig Ali (1,3) and Maruf Mortula (3),

(1) GIS and Mapping Laboratory, American University of Sharjah UAE.
(2) Laboratoire de recherche Modélisation analyse et commande de systèmes- MACS, Ecole Nationale d'Ingénieurs de Gabes – ENIG, Université de Gabes Tunisia.
(3) Civil Engineering Department, American University of Sharjah UAE

myahya@aus.edu;
atarig@aus.edu;
mmortula@aus.edu

Abstract— **Speckle filtering in synthetic aperture radar polarimetry (PolSAR) images is essential for the extraction of significant information for homogeneous extended targets. Obtaining good compromise between high equivalent number of looks (ENL) and spatial detail preservation remains a challenge. In this paper, the filtering performances are improved by hybridizing the iterative minimum mean square error (IMMSE) filter and the Lee Sigma filter. Real SAR data were used to study the effectiveness of the proposed hybrid scheme.**

***Index Terms*— IMMSE filter, Lee Sigma filter, PolSAR, Speckle.**

I. INTRODUCTION

THE synthetic aperture radar (SAR) polarimetry (PolSAR) plays an important role in the analysis and the characterization of the Earth's surface. However, due to the coherent record of echoes, PolSAR data are affected by speckle noise which is one of the major problems of the SAR imagery and which should be filtered correctly. In fact, speckle filtering has a great impact on scene interpretation. In particular, an insufficient averaging generates biased information [1] and overaveraging degrades the spatial resolution [2]. Therefore, it is essential to increase the equivalent number of looks (ENL) without blurring spatial details.

Several methods have been proposed to reduce speckle in PolSAR images. The most popular method is the boxcar filter, also known as multilooking process [2]. It consists in an incoherent averaging of the covariance or the coherency matrices of neighboring pixels. The advantages of the boxcar filter are its high ability to reduce the speckle, its simplicity, and its computational effectiveness. However, its main weakness lies in the spatial resolution degradation. Novak and Burl [3] derived the polarimetric whitening filter (PWF) by optimally combining all the elements of the polarimetric covariance matrix. The PWF produces a single combined intensity image. Lopes and Sery [4] generalized the PWF for multilook data. Based on the multiplicative noise model, Lee *et al* derived an algorithm that generated speckle-reduced PolSAR images by using the criterion of the minimum mean square error (MMSE) [5]. Lee et *al* improved the last approach and applied it in very high resolution PolSAR data [6]. C. López-Martínez and X. Fàbregas [7] demonstrated that the elements of the covariance matrix are affected by the combination of multiplicative and additive noise sources depending on the correlation between polarimetric channels. Based on this model, they proposed a filtering scheme in which the elements of the covariance matrix are filtered separately [8]. An iterative MMSE (IMMSE) filter has been introduced to filter PolSAR images [9]. The state of the art of PolSAR speckle filters and comparisons between them can be found in [10-12].

The objective of this study is the improvement of the speckle filtering by hybridizing IMMSE filter [9] and the Lee Sigma filter [6].

II. SAR POLARIMETRY

Generally, PolSAR data are represented by linear basis vector as:

$$\Omega = \left[S_{hh} \ \ \sqrt{2} S_{hv} \ \ S_{vv} \right]^{t}. \qquad (1)$$

h and v denote the horizontal and vertical polarization, respectively. The superscript "t" indicates matrix transpose. The *span* which represents the total power of a pixel is defined as [2]

$$span = \left| S_{hh}^{2} \right| + 2\left| S_{hv}^{2} \right| + \left| S_{vv}^{2} \right|, \qquad (2)$$

where |.| is the module operation. The covariance matrix C is

$$C = E\left(\Omega \, \Omega^{*t} \right), \qquad (3)$$

where $E(.)$ is the mathematical expectation and "*" denotes the complex conjugation. The eigendecomposition of the coherence matrix leads to the definition of entropy H the anisotropy A and alpha angle α [13]. H and A give a measure of the scene heterogeneity while α indicates the type of the scattering mechanism.

III. INLP FOR POLSAR FILTERING

A) The polarimetric Sigma filter [6].

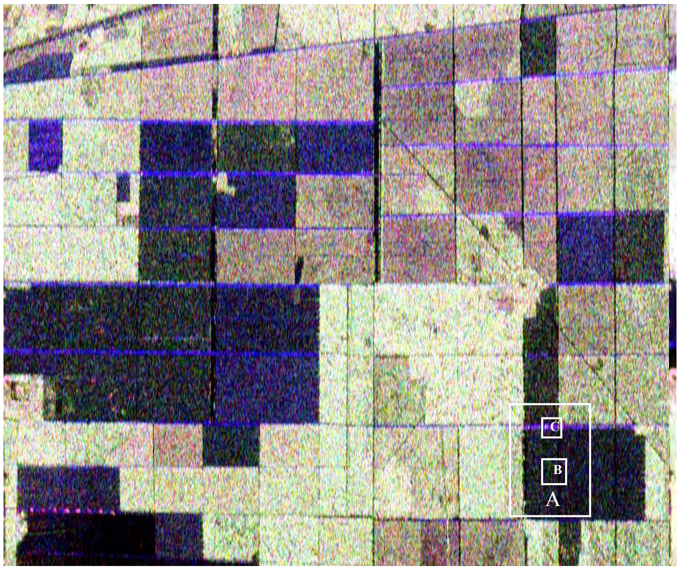


Fig. 1 Pauli coded image: a) Les-Landes, B and C zones were used to compute the ENL and the EPD-ROA, respectively.

TABLE I:PERFORMANCES OF THE FILTERS USING LES-LANDES IMAGE.

	ENL(hh)	*EPD$_H$(hh)*	*EPD$_V$(hh)*
IDAN	13.9980	0.7647	0.7445
Original IMMSE	***20.9791***	0.8020	0.7827
Lee Sigma	20.7267	0.7852	0.7684
Improved IMMSE	19.3276	***0.8115***	***0.7984***

The pixel $y(i)$ of one diagonal element of the covariance matrix is affected by a multiplicative noise as

$$y(i) = x(i)\, v(i), \tag{4}$$

x is the noise-free image to be estimated, and v is the speckle noise with unit mean and standard deviation σ_v [2].

In the polrimetric Lee Sigma filter [6], the filtered pixel $\hat{x}(i)$ is expressed as

$$\hat{x}(i) = \bar{y}(i) + b(i)\left(y(i) - \bar{y}(i)\right), \tag{5}$$

where

$$b(i) = \frac{\operatorname{var}(x(i))}{\operatorname{var}(y(i))}, \tag{6}$$

and

$$\operatorname{var}(x(i)) = \frac{\left(\operatorname{var}(y(i)) - \bar{y}^2(i)\sigma_v^2\right)}{\left(1+\sigma_v^2\right)}, \tag{7}$$

where $\bar{y}(i)$ and $\operatorname{var}(y(i))$ were the mean and the variance of $y(i)$, respectively. A moving window W_1 was applied. Pixels within the sigma range $\left(n_1 y(i), n_1 y(i)\right)$ were included in computing $\hat{x}(i)$ in (5), where n_1, n_2 define the bounds of the sigma range. In the polarimetric Lee Sigma filter [6], the filtered covariance matrix is expressed as

$$\hat{X}_1(i) = \bar{C}(i) + b(i)\left(C(i) - \bar{C}(i)\right) \tag{8}$$

The parameter b is computed from the span image

B) The original Polarimetric IMMSE filter [9]

The filtered covariance matrix is computed using the following iterative filtering procedure:

$$\hat{X}_0(i) = \bar{C}(i), \tag{9}$$

$$\hat{X}_{k+1}(i) = \hat{X}_k(i) + b_k(i)\left(C(i) - \hat{X}_k(i)\right). \tag{10}$$

The parameter $b_k(i)$ is expressed as

$$b_k(i) = \frac{\operatorname{var}(\hat{x}_k(i))}{\left((1+\sigma_v^2)\operatorname{var}(\hat{x}_k(i)) + \hat{x}_k^{\,2}(i)\sigma_v^2\right)} \tag{11}$$

C) The improved Polarimetric IMMSE filter

In the original IMMSE filter [9], the boxcar filter is applied as initial filter. The main drawback of boxcar filter is the blurring of spatial details. So that the iterative procedure requires high number of iterations to retrieve the spatial information which reduced the speckle filtering level in homogeneous areas. To improve the filtering performance, the authors proposed a filtering scheme by hybridizing two polarimetric filters. The iterative filter is initialized by The Lee Sigma filter [6]. Then, to enhance the spatial details the iterative filter is applied for few iterations.

The improved IMMSE procedure is described as

i. Compute $\hat{X}_0$ image using the Lee Sigma filter.

   For a given pixel of the *hh* image

ii. Compute $b_{k,hh}(i)$ using (11).

   Repeat steps ii for *hv* and *vv* images

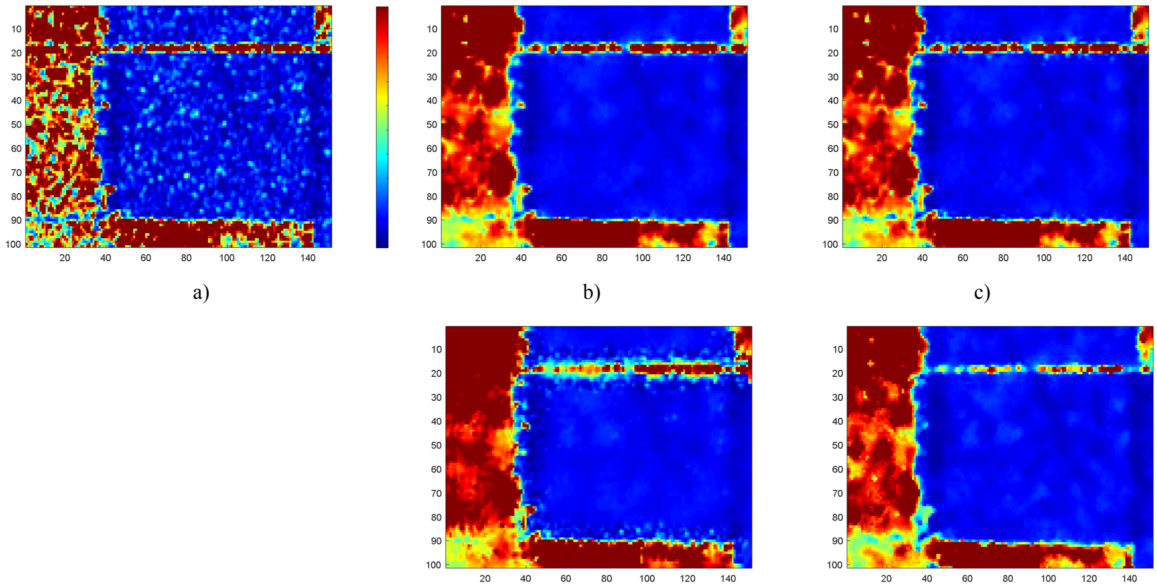
iii. Compute $b_k(i)$

$$b_k(i) = \max\left(b_{k,hh},\ b_{k,hv},\ b_{k,vv}\right) \tag{12}.$$

iv. Update the filtered pixel using (10)

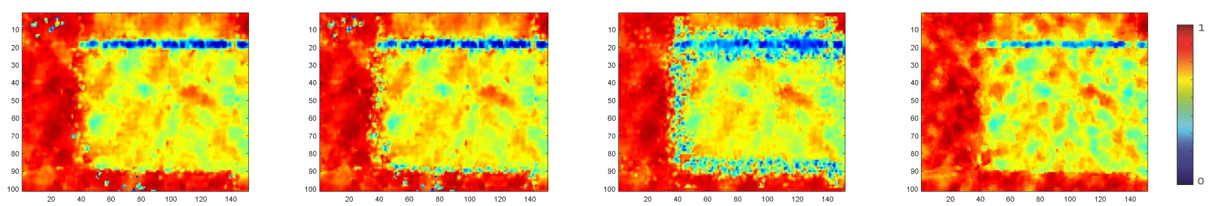
v. Apply the process for all pixels of the image.

vi. Repeat ii to v N iterations.



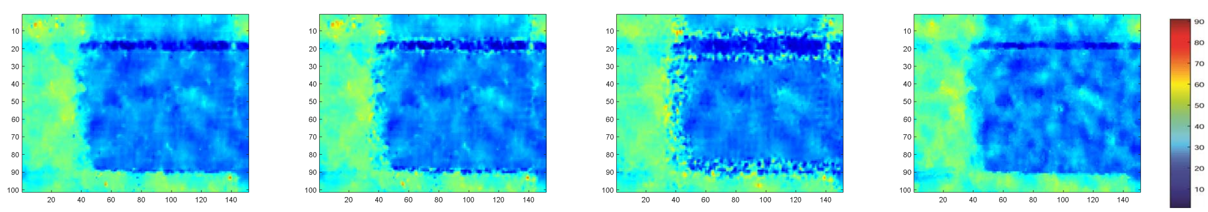
a) b) c) d) e)

Fig. 2: Span images A zone: a) Original, b) Lee Sigma, c) Improved IMMSE, d) Original IMMSE, d) IDAN



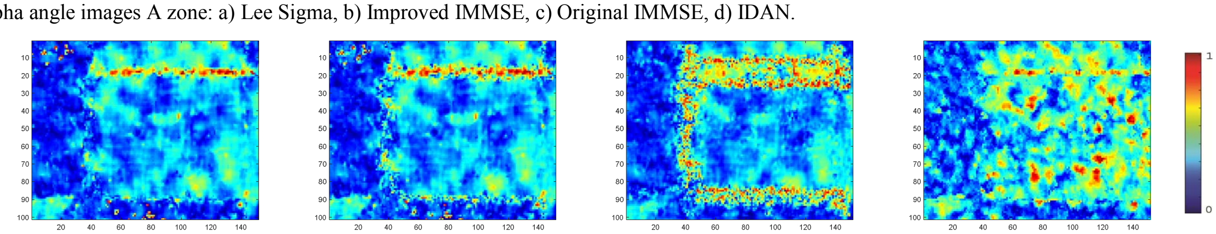
a) b) c) d)

Fig. 3: Entropy images A zone: a) Lee Sigma, b) Improved IMMSE, c) Original IMMSE, d) IDAN



a) b) c) d)

Fig. 4: Alpha angle images A zone: a) Lee Sigma, b) Improved IMMSE, c) Original IMMSE, d) IDAN.



a) b) c) d)

Fig. 5: Anisotropy images A zone: a) Lee Sigma, b) Improved IMMSE, c) Original IMMSE, d) IDAN.

IV. EXPERIMENTAL RESULTS

To illustrate the effectiveness of the improved IMMSE method, Les-Landes PolSAR image is tested. These data were collected by the National Aeronautics and Space Administration Jet Propulsion Laboratory (NASA/JPL) Airborne SAR (AIRSAR).

A. Parameter Setting

For the Lee Sigma filter [6]: window target 3, window filter 9 and sigma range 0.9. For the IDAN filter [14]: window size row (50). Proposed hybrid filter: $\hat{X}_0(i)$ (Lee Sigma filter window filter 11 and sigma range 0.9), number of iterations N=3). Original IMMSE filter: $\hat{X}_0(i)$ (Boxcar 11*11), number of iterations (N=7).

B. *Evaluation Criteria Numerical improvements of the IMMSE Filter*

To evaluate the performances of the implemented PolSAR speckle filtering algorithms quantitatively in terms of speckle reduction level, the equivalent number of looks ENL is chosen.

$$ENL(i) = \frac{\left(\bar{\hat{x}}(i)\right)^2}{\mathrm{var}(\hat{x}(i))}. \quad (13)$$

To illustrate the algorithm validity in structural feature retaining, the Edge Preservation Degree based on the Ratio of Averages (*EPD-ROA*) is used [15]. The *EPD-ROA* in horizontal direction is:

$$EPD-ROA_H(i) = \frac{\sum_{m,n} \left|\hat{x}(m,n)/\hat{x}(m,n+1)\right|}{\sum_{m,n} \left|y(m,n)/y(m,n+1)\right|}, \quad (14)$$

where m and n are the xy coordinates of the pixel in the selected zone, respectively. $EPD\text{-}ROA_V$ is obtained by substituting in (14) the indexes $(m,n+1)$ by $(m+1,n)$. For original image, EPD-ROA=1. When the EPD-ROA is closer to one, it means better ability of spatial detail preservation

To evaluate PolSAR data preservation, the elements of the covariance matrix, the eigenvalues, Cloude-Pottier parameters [13], i. e. entropy H, the anisotropy A and alpha angle α, were assessed. The *span* and Pauli decomposition images are considered for visual criterion of intensity PolSAR data filtering

C. *Results.*

Fig. 2 displays the filtered span images of A zone. The IDAN filter blurred spatial details considerably. The original IMMSE demonstrated better spatial details preservations but the line is smoothed to some extent. The Lee Sigma filter preserved better these lines. The improved IMMSE ensured the highest spatial resolution. The Lee Sigma, the original and the improved IMMSE filter visually show the same speckle reduction level whereas in the IDAN filter the speckle noise persisted. Table I confirms visual interpretations where the improved IMMSE filter produced the best compromise between ENL and EPD-ROA. Figs. 3, 4 and 5 display the entropy the alpha angle and the anisotropy images of A zone. The line which is characterized by simple reflection (H=0 and α=0°) is smoothed by the original IMMSE and IDAN whereas the hybrid iterative filter enhanced it. The ability of Lee Sigma filter and the hybrid IMMSE method in terms of speckle reduction and bias compensation in the extended homogeneous areas are comparable. Nevertheless, the improved IMMSE showed better spatial detail preservation.

V. **CONCLUSION**

This study addressed the enhancement of PolSAR speckle filtering. The filtering performances are improved by hybridizing the iterative minimum mean square error (IMMSE) filter and the Lee Sigma filter**.** Comparisons with IDAN, Lee Sigma and the original IMMSE filters demonstrated the effectiveness of the improved IMMSE method.

ACKNOWLEDGMENT

The authors would like to thank the Smart City Research grant from American University of Sharjah, UAE, Grant EN0-282 and EN0-284. They would also thank the European Space Agency (ESA) for providing PolSARpro 6.0 and NASA GPL for providing PolSAR data.

References

[1] M. Yahia and T. Aguili, "Characterization and correction of multilook effects on eigendecomposition parametrers in PolSAR images," *IEEE Trans. Geosci. Remote Sens.*, vol. 53, no. 9, pp., accepted March 16, 2015.

[2] C. Oliver and S. Quegan, "Understanding synthetic aperture radar Images," Boston, MA: Artech House, 1998.

[3] L. M. Novak, M. C. Burl, and W. W. Irwing, "Optimal polarimetric processing for enhanced target detection," *IEEE Trans. Aerosp. Electron. Syst.*, vol. 29, no. 1, pp. 234–243, Jan. 1993.

[4] A. Lopes and F. Sery, "Optimal speckle reduction for product model in multilook polarimetric SAR imagery and the Wishart distribution," *IEEE Trans. Geosci. Remote Sens.*, vol. 35, no. 3, pp. 632–647, May 1997.

[5] J. S. Lee, M. R. Grunes, and G. De Grandi, "Polarimetric SAR speckle filtering and its implication for classification," *IEEE Trans. Geosci. Remote Sens.*, vol. 37, no. 5, pp. 2363–2373, Sep. 1999.

[6] J. S. Lee, T. L. Ainsworth, Y. Wang, and K. S. Chen, "Polarimetric SAR speckle filtering and the extended sigma filter," *IEEE Trans. Geosci. Remote Sens.*, vol. 53, no.3, pp. 1150–1160, March. 2015.

[7] C. López-Martínez and X. Fàbregas, "Polarimetric SAR speckle noise model," *IEEE Trans. Geosci. Remote Sens.*, vol. 41, no. 10, pp. 2232–2242, Oct. 2003.

[8] C. López-Martínez and X. Fabregas, "Model-based polarimetric SAR speckle filter," *IEEE Trans. Geosci. Remote Sens.*, vol. 46, no. 11, pp. 3894–3907, 2008.

[9] T. Hamrouni, M. Yahia, and R. Abdelfattah "PolSAR speckle filtering using iterative MMSE," International Geoscience and Remote Sensing Symposium IGARSS, pp.637-640, 2018.

[10] J. S. Lee, T. L. Ainsworth, and Y. Wang, "On polarimetric SAR speckle filtering," in *Proc. IEEE Int. Geosci. Remote Sens. Symp*, 2012, pp. 111-114.

[11] S. Foucher, T. Landry, C. López-Martínez, F. Charbonneau, L. Gagnon, "An evaluation of PolSAR speckle filtering on compact-Pol images," in *Proc. IEEE Int. Geosci. Remote Sens. Symp*, 2012, pp. 5089- 5092.

[12] S. Foucher, and C. López-Martínez,, "Analysis, evaluation, and comparison of polarimetric SAR speckle filtering techniques," *IEEE Trans. Image Process.*, vol. 23, no. 4, pp. 1751–1764, Apr. 2014.

[13] S. Cloude and E. Pottier, "A review of target decomposition theorems in radar polarimetry," *IEEE Trans. Geosci. Remote Sens.*, vol. 34, no. 2, pp. 498–518, Mar. 1996.

[14] G. Vasile, E. Trouve, J. S. Lee, and V. Buzuloiu, "Intensity-driven-adaptive-neighbourhood technique for polarimetric and interferometric parameter estimation," *IEEE Trans. Geosci. Remote Sens.*, vol. 44, no. 6, pp. 1609–1621, Jun. 2006

[15] H. Feng, B. Hou, and M. Gong, "SAR image despeckling based on local homogeneous-region segmentation by using pixel-relativity measurement," IEEE Trans. Geosci. Remote Sens., vol. 49, no.7, pp.2724-2737, Jul. 2011.