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SPECKLE MODELING AND TURBO FILTERING OF POLSAR IMAGES

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Introduction

PolSAR radar images are affected by a granular multiplicative noise called speckle. This noise degrades the quality of these images and makes it difficult to interpret. That is why a polarimetric filtering is necessary.

In this work, we are interested in modeling the speckle in the off-diagonal terms of the covariance matrix and filter these terms with adjusting the filtering method already developed for the diagonal terms.

Our objective is to adapt the filtering method called Turbo to filter PolSAR images containing noise that is not multiplicative or additive. The principle of Turbo filter is combining two complementary filters: the refined Lee filtering and the wavelet filtering. One filter can boost up the results of the other.

Two test areas were considered in this study, the area of Oberpfaffenhofen located in Munich (Germany) in P-band airborne polarimetric mode (E-SAR) and an area located in Algiers (Algeria) in C-band spaceborne polarimetric mode (RADARSAT-2).

Speckle Noise Characteristics

- What Effects does it have to SAR Images ?
  - ✓ Low Contrast
  - ✓ No Clear boundary
  - ✓ Loss of Fine features

- Why Speckle Noise is different ?

y = Measured Pixel Value

x = Actual Pixel Value

n = Noisy Pixel Value

$$y = x + n$$

- Additive Noise (e.g. Gaussian Noise)

$$y = xn$$

- Multiplicative Noise (e.g. Speckle Noise)

- What about Noise Statistics ?
  - ✓ Defined by standard deviation of Noise σ_v
  - ✓ Follows the Rayleigh, exponential, Gamma … distribution depending type of image

Speckle Noise Characteristics

In the case of polarimetric SAR images, the measures are:

- The **complex scattering matrix *S*** of a medium with 04 polarizations. In the linear polarization base, it can be expressed as:

$$S = \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix}$$

- For the reciprocal backscattering case $S_{hv} = S_{vh}$, the **scattering vector *K* which represents the polarimetric scattering information** can be expressed as:

$$K = \left[S_{hh}, \sqrt{2}S_{hv}, S_{vv}\right]^T$$

- The polarimetric scattering information also can be represented by a **covariance matrix**:

$$C = KK^{*T} = \begin{bmatrix} |S_{hh}|^2 & \sqrt{2}S_{hh}S_{hv}^* & S_{hh}S_{vv}^* \\ \sqrt{2}S_{hv}S_{hh}^* & 2|S_{hv}|^2 & \sqrt{2}S_{hv}S_{vv}^* \\ S_{vv}S_{hh}^* & \sqrt{2}S_{vv}S_{hv}^* & |S_{vv}|^2 \end{bmatrix}$$

- The diagonal of the covariance matrix which is the total power **called span**, so it has a low level of the speckle noise, and its expression is:

$$span = |S_{hh}|^2 + 2|S_{hv}|^2 + |S_{vv}|^2$$

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Speckle Noise Characteristics

López-Martínez et al (López-Martínez, 2003) have developed a new formulation of the noise model in the off-diagonal images.

They demonstrated that these images are affected by a noise resulting from an addition of two noise types, multiplicative and additive, as shown in the following expression :

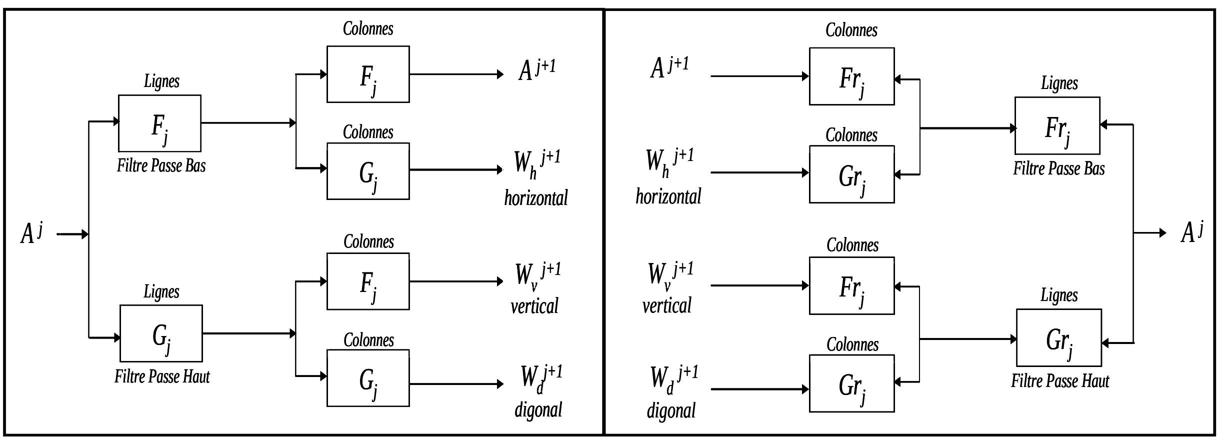
$$HH \cdot VV^* = \underbrace{\psi N_C \bar{z}_{nor} n_m e^{j\phi_x}}_{Multiplicatif\ Term} + \underbrace{\psi\left(|\rho| - N_C \bar{z}_{nor}\right)e^{j\phi_x} + \psi\left(n_{ar} + jn_{ai}\right)}_{Additif\ Term}$$

$$\psi = E\left\{ |HH|^2 \right\} \qquad N_C = \frac{\pi}{4}\, {}_2F_1\left(\frac{1}{2}, \frac{1}{2}; 2; |\rho|^2\right)$$

Filtering by Wavelet Transform

Wavelets are an effective tool for image processing applications. They can identify and analyze the discontinuities in the image at different levels. This property is used for filtering the wavelet coefficients before making the image reconstruction.

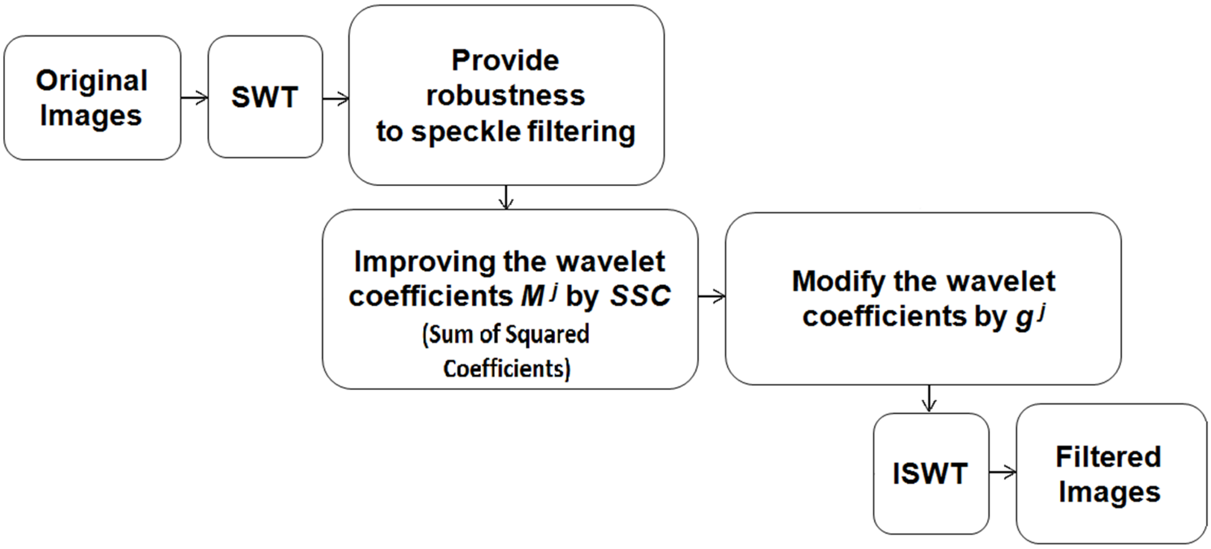
Stationary wavelet transform SWT



Decomposition and reconstruction procedures by SWT

Filtering by Multi-Scale Edge Detection

We can resume the steps of the multi-scale edge detection filtering method in the following block diagram :



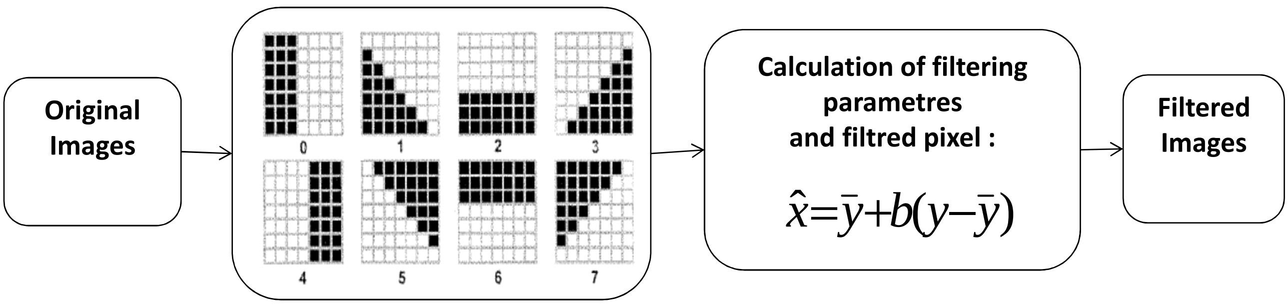
Refined Lee filter

This filter is based on the filtering of the *Span* image to obtain the two principal parameters of filtering:

- the selected window.
- the filtering coefficient b.

$$b = \text{var}(x) / \text{var}(y) \quad \text{with} \quad \text{var}(x) = \left(\text{var}(y) - \bar{y}^2\sigma^2\right) / \left(1+\sigma^2\right)$$

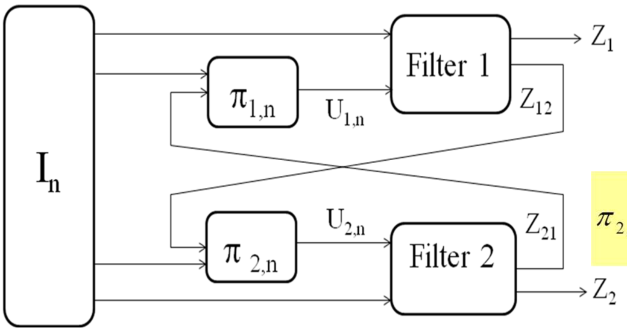
In this method, we identified eight windows and one among them is selected to filter the central pixel. The white part of each window is used in the filtering calculation.



Turbo filter principle

In this method, two different filters are chosen in a way that their performances complement each other.

- The filter 1 (wavelet filter) should have a tendency to reduce the noise with a good edge preservation, and must treat the noise of residue images to retrieve useful information.
- The filter 2 (refined Lee filter) should result in a speckle reduction with a good estimation of the polarimetric parameters.



$$\pi_{1,n} \overset{\Delta}{=} \begin{cases} U_{1,n} = \left| I_n / Z_{21,n} \right| & \text{for diagonal terms} \\ U_{1,n} = \left| \dfrac{I_n}{\psi_n \bar{z}_{n,k}} \right| & \text{for off-diagonal terms} \end{cases}$$

$$\pi_{2,n} \overset{\Delta}{=} \begin{cases} U_{2,n} = Z_{12,n} Z_{21,n} & \text{for diagonal terms} \\ U_{2,n} = \psi_n \bar{z}_{nor,n} Z_{12,n} e^{j\phi} & \text{for off-diagonal terms} \end{cases}$$

The steps of the Turbo filter method are:

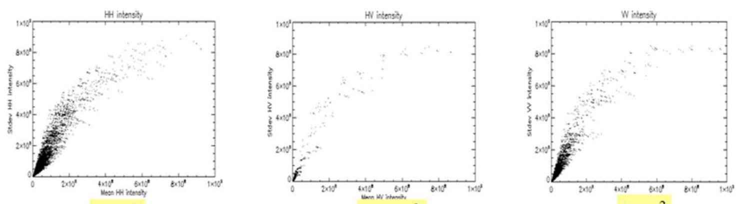
- Apply SWT on the original image I_n for the initialization, Z_{21} is the low-frequency image A^j.
- Calculate the residue image U_1 from the operator π_1 and apply Filter 1 on U_1 and I_n.
- Calculate the residue image U_2 from the operator π_2 and apply Filter 2 on U_2 and I_n.
- Stop the iterations when change in Z_{21} becomes small or go to step 2 for another iteration.

Results Evaluation

The evaluation of each filter is based on the following principal criteria:

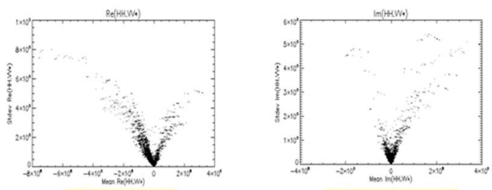
- Its capacity to smooth the homogeneous areas,
- Its aptitude to preserve contours,
- Its capacity to preserve polarimetric information.

The scatter plotting of the standard deviation versus the mean



$|HH|^2$ $|HV|^2$ $|VV|^2$

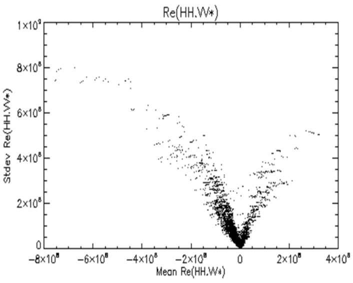
Multiplicative Noise



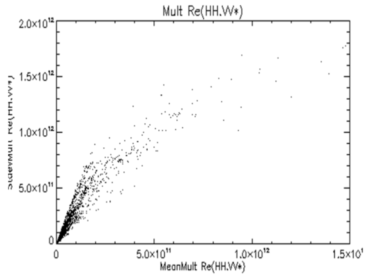
$\Re\{HH \cdot VV^*\}$ $\Im\{HH \cdot VV^*\}$

Neither Additive Nor Multiplicative Noise

Results Evaluation

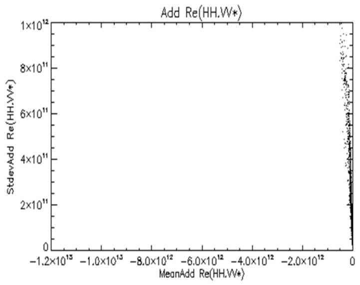


$\Re\{HH\cdot VV^*\}$



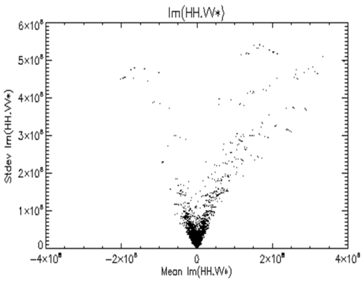
$\Re\{HH\cdot VV^*\}$

Multiplicative Part

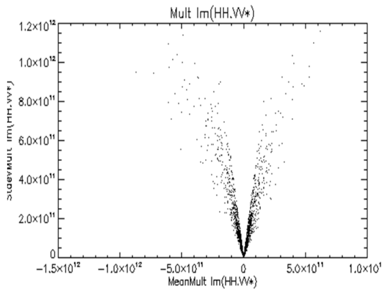


$\Re\{HH\cdot VV^*\}$

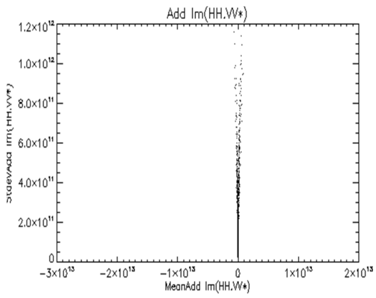
Additive Part



$\Im\{HH\cdot VV^*\}$



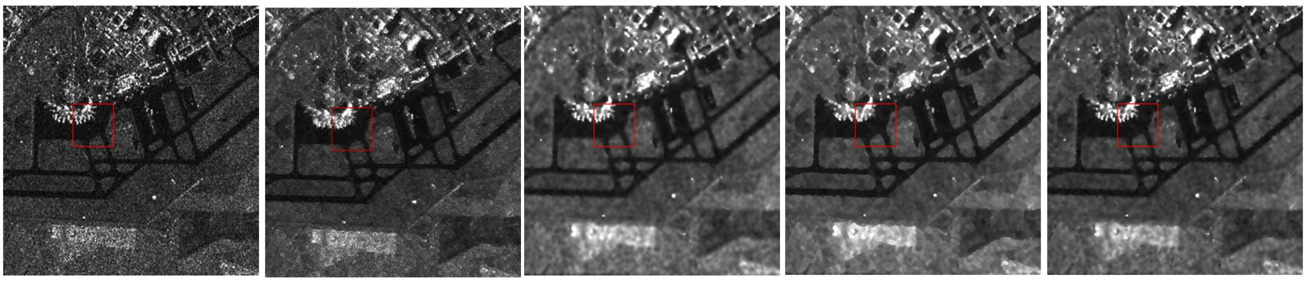
$\Im\{HH\cdot VV^*\}$



$\Im\{HH\cdot VV^*\}$

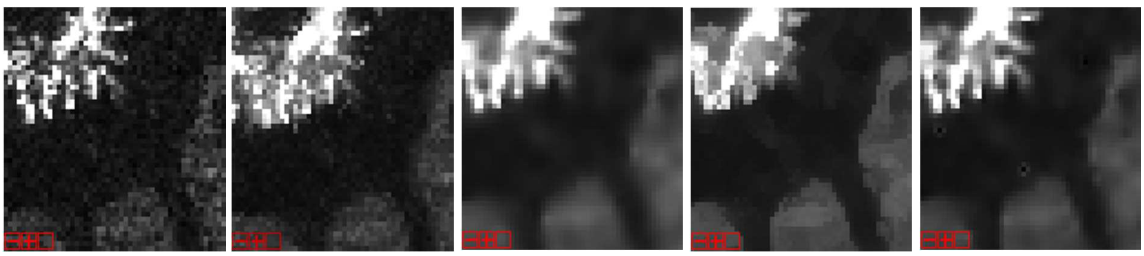
Results Evaluation

Span images (Algiers)



Original | Refined Lee | Wavelets | Turbo Lee | Turbo Wav.

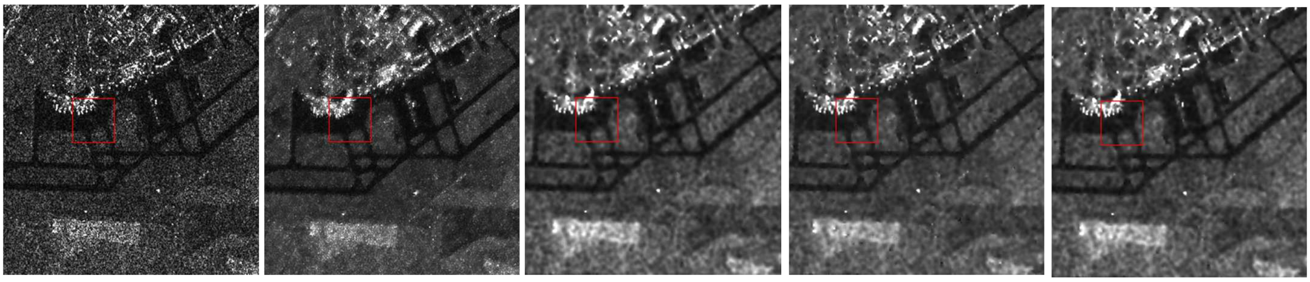
Zoom of Span images (Algiers)



Original | Lee | Wavelets | Turbo Lee | Turbo Wav.

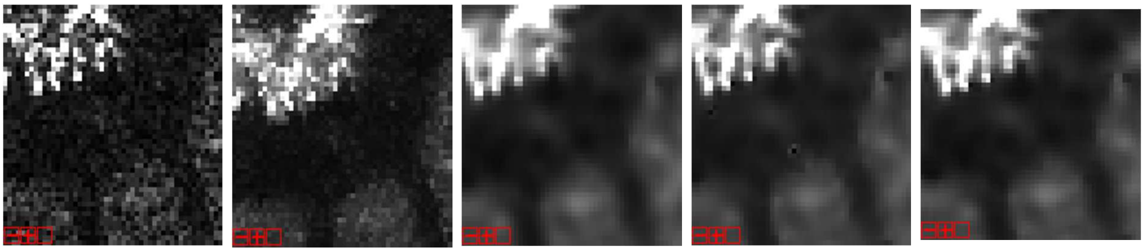
Results Evaluation

$|HH \cdot VV^*|$ images (Algiers)



Original | Lee | Wavelets | Turbo Lee | Turbo Wav.

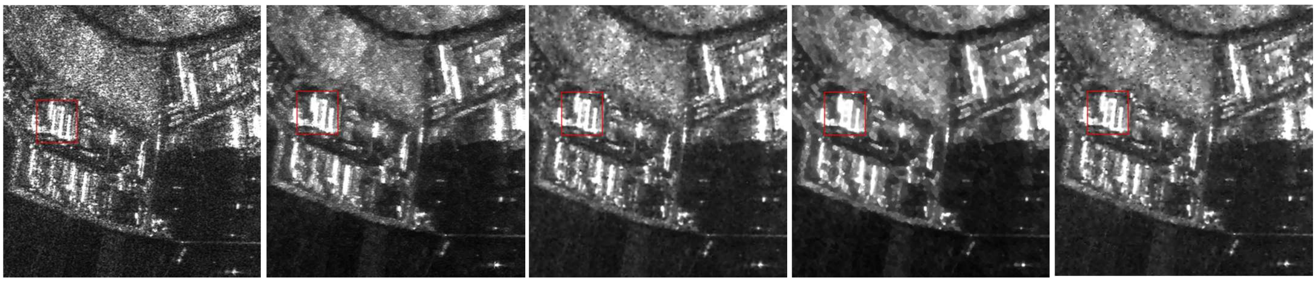
Zoom of $|HH \cdot VV^*|$ images (Algiers)



Original | Lee | Wavelets | Turbo Lee | Turbo Wav.

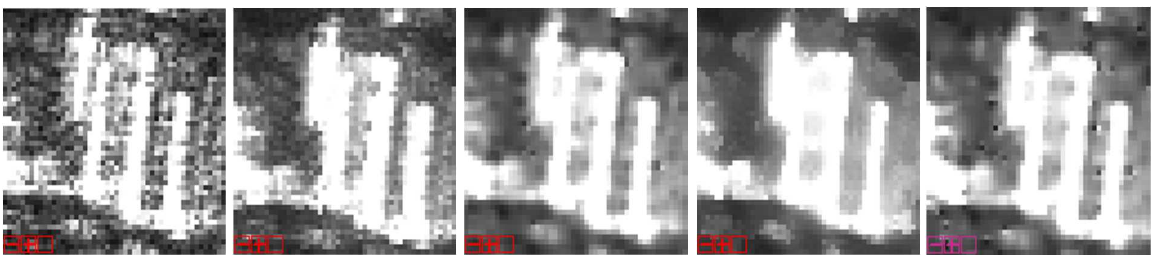
Results Evaluation

Span images (Munich)



Original | Lee | Wavelets | Turbo Lee | Turbo Wav.

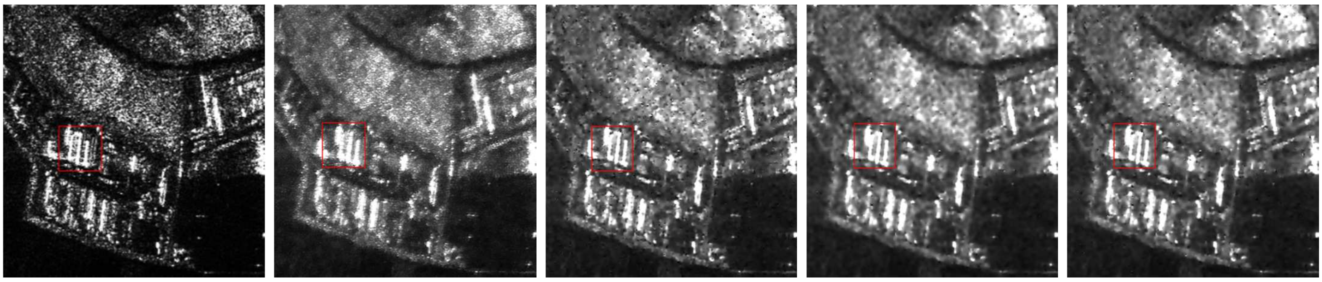
Zoom of Span images (Munich)



Original | Lee | Wavelets | Turbo Lee | Turbo Wav.

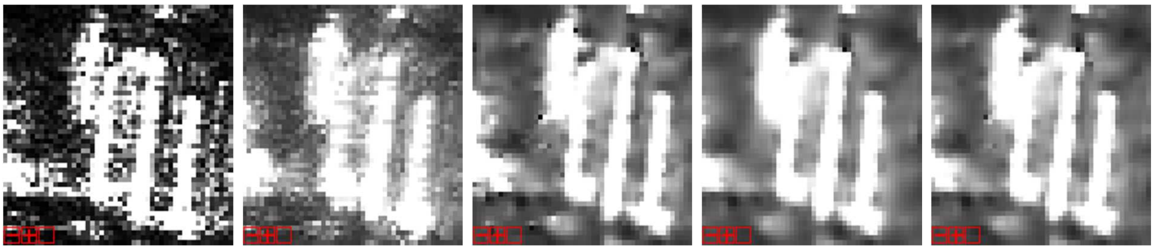
Results Evaluation

$|HH \cdot VV^*|$ images (Munich)



Original | Lee | Wavelets | Turbo Lee | Turbo Wav.

Zoom of $|HH \cdot VV^*|$ images (Munich)



Original | Lee | Wavelets | Turbo Lee | Turbo Wav.

Results Evaluation

- ***Statistical Evaluation:*** ***Evaluation in the homogeneous regions:*** size (20x20) pixels

A good filtering in homogeneous areas is represented by an increase value of ENL.

$$ENL_I = \left(\frac{1}{C_I}\right)^2$$

ENL VALUES IN *SPAN* IMAGES

Areas	Original	Turbo Lee	Turbo SSC
Algiers	2.66	7.26	5.28
Munich	2.17	16.12	11.47

ENL VALUES IN $|HH \cdot VV^*|^2$

Areas	Original	Turbo Lee	Turbo SSC
Algiers	1.07	8.56	4.53
Munich	1.98	14.19	13.12

Overall, the statistical evaluation of the obtained results of Turbo filter showed a great ability to smooth homogeneous areas. Thus, these results follow the conclusions of visual evaluation.

Results Evaluation

Statistical Evaluation: ***Evaluation in the heterogeneous regions:*** *size (10x10) pixels.*

The best filter in terms of edge preservation is the one giving the highest coefficient of variation Cvg.

$$Cvg = \frac{1}{Q}\sum_{i=1}^{Q} Cv_i$$

CVG VALUES IN SPAN IMAGES

Areas	Turbo Lee	Turbo Wav.	Lee	Wavelets
Algiers	1.51	1.28	1.11	1.23
Munich	0.24	0.40	0.35	0.26

CVG VALUES IN $|HH \cdot VV^*|^2$

Areas	Turbo Lee	Turbo Wav.	Lee	Wavelets
Algiers	2.01	1.30	1.09	1.24
Munich	0.21	0.99	0.48	0.65

The best global result in terms of edge preservation is given by the Turbo filter. We also note that the statistical results join well the conclusions of the visual evaluation.

Conclusion and perspectives

The new formulation of the speckle noise model allows to study the noise characteristics of the off-diagonal PolSAR covariance matrix terms and also to know better the used data for the treatment in order to achieve a better result.

According to the results obtained in the evaluation, we concluded that the Turbo filter:

- ✓provides clear images with a much reduced speckle
- ✓presents a good compromise between smoothing homogeneous areas and preserving edges.

And that thanks to the principle of this method which consists in joining together the advantages of the two filters: the refined Lee filter and wavelet filtering.

However, the selection and adjustment of parameters is not obvious, we had to do several tests to obtain a good compromise between smoothing homogeneous areas and preserving edges.


Thank You For Your Attention
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