Fusion of Evidences for Edge Detection in PolSAR Images

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Cronograma

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Introduction

Introduction

PolSAR Image

PolSAR characteristics

- can be on raised platforms, crewed aircraft or not, satellites orbiting the earth or other planets;
- it is a viable and practical imaging technique;
- has a high resolution;
- synthesizes long antenna openings;
- radars produce images day and night;
- climate does not interfere in image capture;
- SAR imaging systems operate in the microwave region of the electromagnetic spectrum, usually between the P-band - and the K-band.

PolSAR Image

PolSAR Applications

- Remote sensing;
- economy
- topography;
- oceanography;
- glaciology;
- agriculture
- geology;
- forests;
- fixed or moving targets;
- environmental monitoring;
- oil spill control;
- moreover, the aid of optical systems.

PolSAR Image

Statistical modeling for PolSAR data

- The complex scattering matrix $\mathbf{S}$:

$$\mathbf{S} = \begin{bmatrix} S_{\mathrm{hh}} & S_{\mathrm{hv}} \\ S_{\mathrm{vv}} & S_{\mathrm{vv}} \end{bmatrix}. \tag{1}$$

- The medium of propagation of waves is reciprocal.

$$\mathbf{s} = [S_{\mathrm{hh}}, S_{\mathrm{hv}}, S_{\mathrm{vv}}]^T$$

.

Statistical modeling for PolSAR data

- The distribution of $\mathbf{s}$ is assumed to be Gaussian circular complex multivariate with zero mean $N_3^C(0, \Sigma)$.
- The probability density function (pdf):

$$f_{\mathbf{s}}(\mathbf{s}; \Sigma) = \frac{1}{\pi^3 |\Sigma|} \exp(-\mathbf{s}^H \Sigma^{-1} \mathbf{s}), \tag{2}$$

  - $|\cdot|$ is the determinant,
  - H denotes the conjugate complex number,
  - Σ is the covariance matrix of $\mathbf{s}$ such that $\Sigma = E[\mathbf{s}\mathbf{s}^H]$,
  - $E[\cdot]$ denotes the expected value.

Statistical modeling for PolSAR data

- The estimated sample covariance matrix:

$$\mathbf{Z} = \frac{1}{L}\sum_{\ell=1}^{L} \mathbf{s}_\ell {\mathbf{s}_\ell}^H, \tag{3}$$

  - $\mathbf{s}_\ell$, $\ell = 1, \ldots, L$,
  - L independent samples of complex vectors distributed as $\mathbf{s}$.

PolSAR Image

Statistical modeling for PolSAR data

- Multilooked Wishart distribution with probability density function:

$$f_{\mathbf{Z}}(\mathbf{Z}; \Sigma_s, L) = \frac{L^{mL} |\mathbf{Z}|^{L-m}}{|\Sigma_s|^L \Gamma_m(L)} \exp(-L \operatorname{tr}(\Sigma_s^{-1} \mathbf{Z})), \tag{4}$$

  - $\operatorname{tr}(\cdot)$ is the trace operator,
  - $\Gamma_m(L)$ is a multivariate Gamma function

$$\Gamma_m(L) = \pi^{\frac{1}{2}m(m-1)} \prod_{i=0}^{m-1} \Gamma(L-i),$$

  - $\Gamma(\cdot)$ is the Gamma function,
  - $m = 3$,
  - $\mathbf{Z} \sim W(\Sigma, L)$,
  - $E[\mathbf{Z}] = \Sigma$.

Edges detection

The following procedure is proposed to detected edges in the hh, hv and vv channels:

- identify the centroid of a region of interest (ROI) in an automatic, semi-automatic or manual manner;
- cast rays from the centroid to the outside of the area;
- collect data around the rays using the Bresenham's midpoint line algorithm, ideally the size of a pixel;
- detect points in the data strips which provide evidence of changes in their statistical properties, i.e., a transition point that defines edge evidence;
- use the Generalized Simulated Annealing (GenSA) method, Ref. [1], to find maximum points in the functions of interest;
- fuse the evidence of detected edges in the hh, hv and vv channels.

PolSAR Image

Maximum Likelihood Estimator (MLE)

- Suppose $\mathbf{X} = (X_1, X_2, \ldots, X_n)^T$ is a random vector distributed according to the probability density function $f(\mathbf{x}, \theta)$ with parameters $\theta = (\theta_1, \ldots, \theta_d)^T$ in the parameter space Θ.
- The likelihood function is

$$L(\theta; \mathbf{X}) = \prod_{i=1}^{n} f(x_i; \theta),$$

- log-likelihood function is

$$\ell(\theta; \mathbf{X}) = \ln L(\theta; \mathbf{X}) = \sum_{i=1}^{n} \ln f(x_i; \theta), \tag{5}$$

- $\widehat{\theta} = \arg\max_{\theta \in \Theta} \ell(\theta; \mathbf{x})$.

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Maximum Likelihood Estimator (MLE) for two regions A and B

- The estimates for the covariance matrices can be found using the maximum likelihood estimator denoted by $\widehat{\Sigma}$, Ref. [2]:

$$\widehat{\Sigma}_I(j) = \begin{cases} j^{-1} \sum_{k=1}^{j} \mathbf{Z}_k & \text{if} \quad I = A, \\ (N-j)^{-1} \sum_{k=j+1}^{N} \mathbf{Z}_k & \text{if} \quad I = B. \end{cases} \tag{6}$$

- likely function

$$L(j) = \prod_{k_1=1}^{j} f_{\mathbf{Z}}(\mathbf{Z}_{k_1}; \widehat{\Sigma}_A, L) \prod_{k_2=j+1}^{N} f_{\mathbf{Z}}(\mathbf{Z}_{k_2}; \widehat{\Sigma}_B, L), \tag{7}$$

- log-likely function

$$\ell(j) = \sum_{k_1=1}^{j} \ln f_{\mathbf{Z}}(\mathbf{Z}_{k_1}; \widehat{\Sigma}_A, L) + \sum_{k_2=j+1}^{N} \ln f_{\mathbf{Z}}(\mathbf{Z}_{k_2}; \widehat{\Sigma}_B, L). \tag{8}$$

Maximum Likelihood Estimator (MLE)

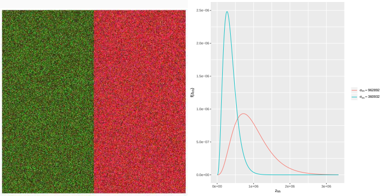
- After algebraic manipulations on each term of the summation, it is obtained:

$$\begin{aligned}\ell(j) = {} & N\,[mL(\ln L - 1) - \ln \Gamma_m(L)] \\ & - L\left[j \ln |\widehat{\Sigma}_A(j)| + (N-j) \ln |\widehat{\Sigma}_B(j)|\right] \\ & + (L-m) \sum_{k=1}^{N} \ln |\mathbf{Z}_k|. \end{aligned} \quad (9)$$

- The argument of the maximum $\widehat{\jmath}$ is the edge evidence that will be used in our fusion methods.

PolSAR Image

Application in simulated images

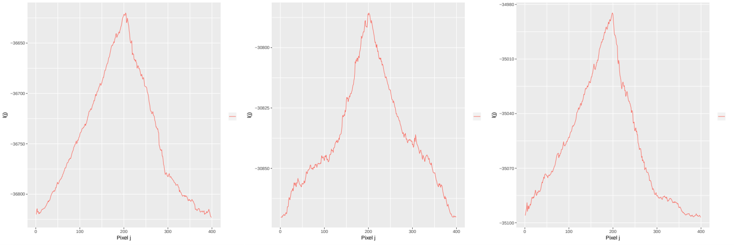


(a) Pauli decomposition

(b) Marginal densities of the hh channel

Figura 1: Edges evidences

Application in simulated images

- 

(a) Channel hh (b) Channel hv (c) Channel vv

Figura 2: Edges evidences

PolSAR Image

Application in simulated images

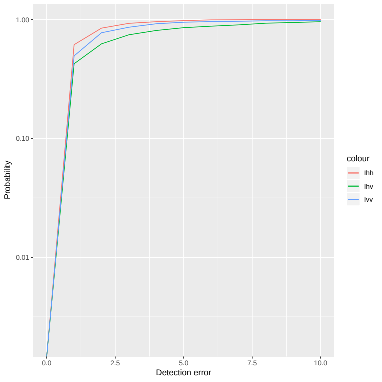


Figura 3: Probability of detecting edges evidences.

Methods of fusion of edge evidence

- $$IF(x, y) = \frac{1}{nc} \sum_{i=1}^{nc} IE_i(x, y), \tag{10}$$

PolSAR Image

Methods of fusion of edge evidence

- Stationary wavelet transform – SWT
- calculate the SWT decomposition by getting I_{HH}, I_{HL}, I_{LH} and I_{LL} for each channel (image);
- in the decompositions I_{HH}, obtain the arithmetic mean of all channels, pixel by pixel. In the decompositions I_{HL}, I_{LH} and I_{LL}, the maximum between each channel is found, pixel by pixel, leaving a new decomposition $\overline{L}_{\mathrm{HH}}$, $\overline{I}_{\mathrm{HL}}$, $\overline{I}_{\mathrm{LH}}$ and $\overline{I}_{\mathrm{LL}}$;
- perform the inverse SWT transformation. The image is obtained by fusing the edge evidence $IF(x, y)$.

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Methods of fusion of edge evidence

- Principal component analysis – PCA
- organize the data in such a way that each image has a column vector, forming a Y matrix of dimension $l \times nc$, where $l = mn$, the lines times the columns of the matrices to be used in the fusion;
- calculate the average of the elements of these columns, generating a vector dimension of $1 \times nc$;
- subtract the average of each column from the Y matrix, resulting in X, a matrix of the same dimension of Y;
- find C, the covariance matrix of X;
- calculate its eigenvalues Λ and eigenvectors D, and sort the eigenvalues and eigenvectors in descending order. The matrices generated by the eigenvalues, on the main diagonal, and the eigenvectors placed in column, have dimensions $nc \times nc$;
- compute the components $P_i = {V_i}^{-1} \sum_{i=1}^{l} V_i$ with $i = 1, \ldots, nc$;
- fuse $IF(x, y) = \sum_{i=1}^{nc} P_i IF_i(x, y)$, recalling that $\sum_{i=1}^{nc} P_i = 1$

Methods of fusion of edges evidence

- ROC statistics
- obtain the evidence of edges in the channels, and store it in E_i matrices, with $i = 1, \ldots, nc$ in a binary way;
- define a V edge frequency matrix. The V matrix is generated by adding the evidence of E_i edges;
- use thresholds ranging from $t = 1, \ldots, nc$ generating M_t matrices;
- compare each M_t, fixed with all E_i, find the confusion matrix to generate the ROC curve. The point of the ROC curve closest (in the sense of the Euclidean distance) to the diagnostic line will have its threshold considered optimal;
- the M_t matrix which corresponds to the threshold closest to the diagnostic line is the result of the fusion.

PolSAR Image

Numerical results

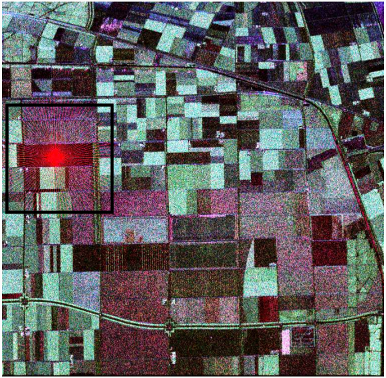
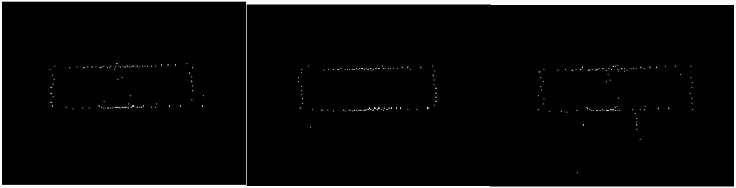
- 

Figura 4: Region of interest (ROI) in the image of Flevoland.

Numerical results

- 

(a) Evidences in channel hh

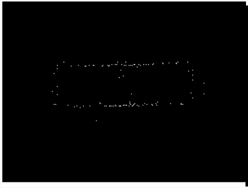
(b) Evidences in channel hv

(c) Evidences in channel vv

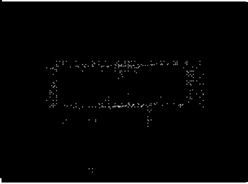
Figura 5: Edges evidences

PolSAR Image

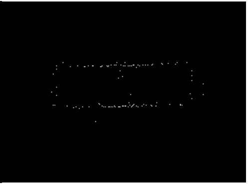
Methods of fusion of edge evidence

- 

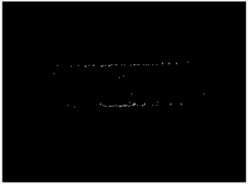
(a) Average fusion



(b) SWT fusion



(c) PCA fusion



(d) ROC fusion

Figura 6: Fusion methods

Conclusion

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Estudo de cores

PolSAR Image

Numerical results

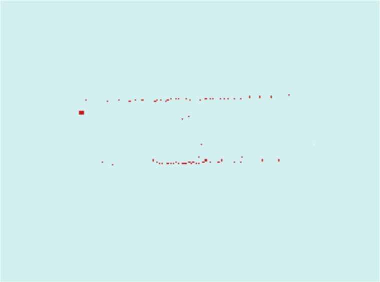


Figura 7: Blue red.

Numerical results

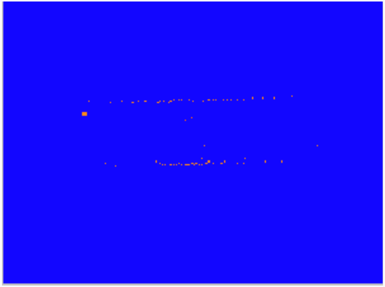
- 

Figura 8: DarkBlue orange.

Numerical results

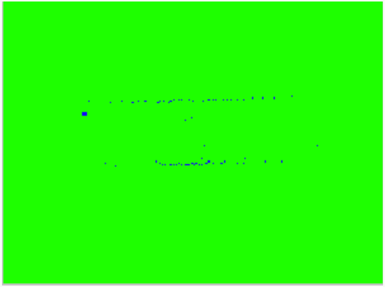
- 

Figura 9: Green blue.

Numerical results

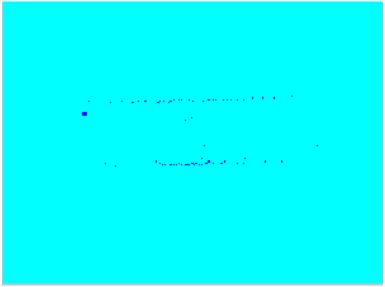
- 

Figura 10: lightblue blue.

Numerical results

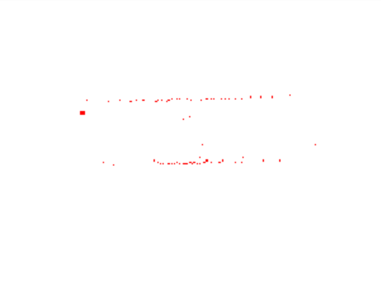
- 

Figura 11: white red.

Numerical results

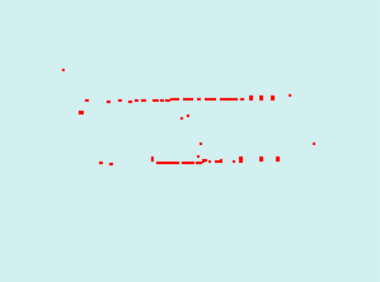
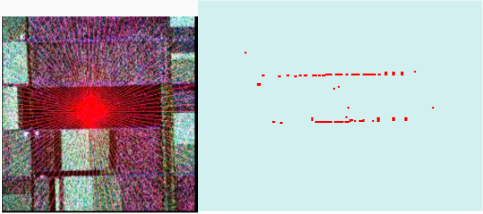
- 

Figura 12: Blue red com pixels aumentados.

Application in simulated images



(a) Pauli decomposition

(b) ROC fusion

Figura 13: Edges

- Yang Xiang, S. Gubian, B. Suomela, and J. Hoeng, "Generalized simulated annealing for efficient global optimization: the GenSA package for R." *The R Journal Volume 5/1, June 2013*, 2013. [Online]. Available: https://journal.r-project.org/archive/2013/RJ-2013-002/index.html
- N. R. Goodman, "The distribution of the determinant of a complex wishart distributed matrix," *Ann. Math. Statist.*, vol. 34, no. 1, pp. 178–180, 03 1963. [Online]. Available: http://dx.doi.org/10.1214/aoms/1177704251