LOCAL TEXTURE STATIONARITY INDICATOR FOR FILTERING DOÑANA WETLANDS SAR IMAGES

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ABSTRACT

This paper defines a new operator, named Ds, for local texture stationarity assessment on SAR images. . The aim is to discriminate heterogeneous targets from land cover types of high normalized variance values, as those observed in flooded vegetation areas of Doñana wetlands. Suitable Ds thresholds for such discrimination were estimated for different window sizes through Monte Carlo simulations of synthetic textures. Maximum stationary texture windows were then determined on Doñana ASAR scenes by Ds multi-resolution thresholding and averaging was applied within. Results reveal the substantial degree of smoothing achieved over high variance cover types, while edges among different targets were properly preserved.

Index Terms— Texture stationarity, multi-resolution filtering, SAR, wetlands.

1. INTRODUCTION

Doñana National Park marshes, in south west Spain, constitute a highly dynamic landscape: up to 30,000 ha flood in fall, helophyte vegetation emerges from large part of the water surface during the springtime and all water bodies and vegetation dry up in summer. Flood extent and vegetation development in Doñana were monitored from 2006 to 2009 using Envisat /ASAR images [1]. The scenes were acquired at the seven ASAR incidence angles in order to achieve high observation frequency.

Mapping flood extent and vegetation developmental stage required filtering the ASAR scenes to smooth out backscattering fluctuations owing to speckle and high variance texture. At the end of the winter time, patches of sparse vertically oriented helophyte stalks start coming out from the water surface and yield a strong double boue texture cover nce return. As the stalks develop in height and density their signal increases rapidly [1]. Concurrently, the patches also grow spatially, since new sparse stalks continue to appear around the clutter. Given the accused increment in double bounce return due to moderate helophyte development, neighborhood pixels at comparable phenological stages can yield significant contrast radar returns. As a result, pixel intensities in areas of similar vegetation cover show high intensity fluctuations not attributable only to speckle noise. These areas are referred to as high variance texture areas.

Well established speckle filters, such as Lee's [2], Frost's [3] or Kuan's [4] were developed to reduce only speckle noise, within neighborhoods for which the terrain signal is locally stationary. These algorithms use the normalized variance or coefficient of variation (CV) to measure local stationarity of the terrain radar return or radar cross section (RCS) and different degrees of filtering are used accordingly. When applied to Doñana scenes acquired during the helophyte emerging season, high CV due to strong fluctuations of the RCS leads to reduced filtering, and strong intensity fluctuations remain.

Stochastic methods for texture discrimination are difficult to apply, since they require large enough samples to characterize the textures and helophyte emergence often happen within relatively small clutters. Nevertheless, the observer is able to visually distinguish clutters of approximately isotropic textures, which correspond to areas of similar phenological stage. This paper presents a new geometrical operator, named Ds, which measures the isotropy of pixel intensities within a neighborhood. Such isotropy is used as an indicator of locally stationary texture, and therefore of areas of similar phenology. The Ds indicator is then used in a multi-resolution fashion to determine the largest stationary texture areas in Doñana marshes ASAR scenes and filtering is applied to smooth intensity fluctuations within them.

2. PARAMETER Ds FOR LOCAL TEXTURE STATIONARITY ASSESSMENT

2.1. Definition

Expressions (1), (2) and (3) define the Ds geometrical operator for local texture stationarity assessment on SAR images. In these expressions I stands for pixel value, i, j denote image row and column, N represents the processing neighborhood and Ci, Cj are the image coordinates of the neighborhood geometrical center.

$$D_i = \frac{\sum_i \sum_j \ i \cdot \ I(i,j)}{\sum_i \sum_j I(i,j)}, \quad \forall \, (i,j) \in N \qquad (1)$$

$$D_j = \frac{\sum_i \sum_j j \cdot I(i,j)}{\sum_i \sum_j I(i,j)}, \quad \forall\,(i,j) \in N \qquad (2)$$

$$Ds = \sqrt{(D_i - C_i)^2 + (D_j - C_j)^2} \qquad (3)$$

Ds accounts for the spatial arrangement of the pixel values so that image windows with identical histograms and CV can have different Ds values. Within a stationary neighborhood where pixel intensities are independent realizations of the same probability density function (pdf), backscattering fluctuations have an isotropic spatial distribution and Ds yield low values, as shown in Section 2.2. In presence of two different adjacent targets, the value of Ds increases consistently with their imbalance or contrast (i.e. ratio between targets' mean value).

2.2. Assessment of Ds as a stationarity texture detector

The pdf's of parameter Ds operating over intensity SAR images of different target types, have been estimated through Monte Carlo simulations: a synthetic square image is generated so that pixel values are independent realizations of the same distribution. Homogeneous target intensitites are modeled by a gamma distribution, while the normal distribution is used to generate textured targets. Fig. 1 shows some of the resultant pdf's. It is worth noting that the Ds distribution is independent of the mean intensity, processing window size and even on the target type (homogeneous or textured). Ds pdf depends only on the CV, becoming narrower as the CV decreases.

For homogeneous targets, CV depends exclusively on the image equivalent number of looks. In the case of textured areas, the CV is target dependent and will need to be estimated over the particular land cover type in order to use the appropriate pdf for filtering purposes. In the case of emerging helophytes, it has been observed to vary between 0.8 a 1.0.

The value of Ds over a heterogeneous window comprising pixels of two different gamma or normal distributions has been simulated in presence of straight and irregular, sharp and gentle boundaries, and in the case that the edge is or not centered within the processing window. In the heterogeneous case, the Ds pdf is shifted towards higher Ds values in an amount dependent on the processing window size and contrast between adjacent targets. Fig. 1 shows the Ds pdf of a heterogeneous target of contrast 2 (straight centered edge) computed using 9x9 pixel windows.

When filtering fluctuations in a SAR image, it is necessary to test the stationarity of the processing window, so that the computation of filtered values avoids using pixels from different target types. In order to decide on the stationarity of a pixel neighborhood based on the corresponding Ds value, a threshold needs to be chosen. To evaluate the performance of Ds as a stationarity indicator, the confusion probability of a given Ds threshold has been defined as the average likelihood of miss-recognizing a heterogeneous window as stationary or conversely. The shaded area in Fig. 1, gives graphical interpretation of the confusion probability for threshold 0.50, window size 9x9 and targets contrast 2.

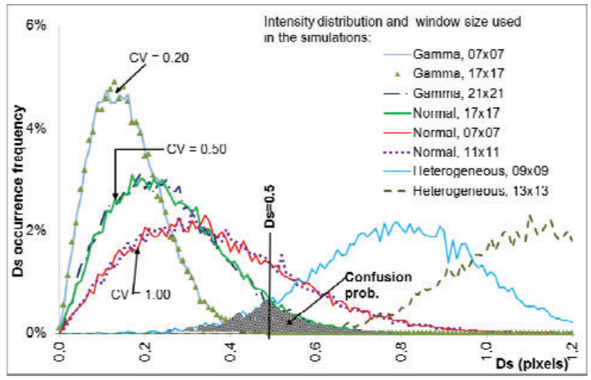

Fig. 1. Ds pdf's obtained through Monte Carlo simulations for different synthetic targets: homogeneous (generated with gamma distributed intensities), textured (generated with normal distribution intensities) and heterogeneous (generated with two adjacent gamma distributions of CV=0.5 and contrast=2).

Given a particular window size and contrast, the best performance threshold will be the one that minimizes the confusion probability. This best threshold coincides with the Ds value where stationary and heterogeneous pdf curves intersect (e.g. value 0.50 for window size 9x9 and contrast 2 in Fig. 1).

Optimal Ds thresholds were computed for different edge geometries and window sizes by minimizing the integral of the confusion probability curves from contrast 1.25 to 4.50. Plots depicting the confusion probability associated to those geometries were produced for their corresponding optimal Ds thresholds. The confusion probability of the CV and the ratio edge detector [5] for the same geometries, and also for their best performance thresholds, was plotted for comparison. This analysis revealed that Ds performance is close to that of the ratio detector for straight geometries, but appreciably better in the case of irregular edges. Ds showed lower confusion probabilities than CV for all simulated geometries.

2.3 Use of Ds for stationarity assessment in multi-resolution filtering

A key issue in multi-resolution speckle filtering is to determine the largest stationary window where the filtering algorithm can be applied. Implementing the Ds operator for this goal requires the use of thresholds dependent on the processing window dimension, so that the best edge presence/absence split value is used at each window size. Optimal thresholds were found by minimizing the integral of the confusion probability for window sizes between 5x5 and 21x21 and different CV's. Knowledge of the best performance threshold trends can greatly assist the selection of these values, which are critical for the quality of the results. These trends have been used in the multi-resolution filtering of Doñana ASAR scenes, presented in the next section.

3. USE OF DS OPERATOR IN THE MULTIRESOLUTION FILTERING OF DOÑANA ENVISAT/ASAR SCENES

Delineation of Doñana cover types required filtering the ASAR scenes to smooth out backscattering coefficient fluctuations. Filtering has been carried out in a multi-resolution fashion: the processing window becomes as large as 21x21 pixels in homogenous or stationary textured areas and is progressively reduced when approaching edges, so that it does not ride over different land cover types. In presence of gradual cover type transitions, the filtering window size adapts to the gradient steepness.

The Ds value has been used to decide on the maximum stationary window. Ds values were computed at every pixel for odd window sizes ranging from 5x5 to 21x21 and referred to as LxL. Then, the optimal set of Ds thresholds as a function of window size is selected depending on the scene ENL for homogeneous areas (e.g. bare soil surfaces), and on the expected CV for other cover types (i. e. helophyte vegetation). The Ds values at each pixel (i,j) are compared to the thresholds of the corresponding window sizes Th(L), starting from LxL=5x5. If Ds(5)<Th(5) then pixel (i,j)'s neighborhood is considered isotropic at least in a 5x5 window. For progressively increasing odd-side windows the conditions (5) and (6) below are tested.

$$Ds(L+2) < Th(L+2), \text{ at pixel (i,j) to be filtered} \quad (5)$$

$$Ds(L)<Th(L), \text{ for all pixels contiguous to (i,j)} \quad (6)$$

Only if both conditions (5) and (6) are satisfied, window (L+2)x(L+2) is considered stationary and the next window size is assessed in a similar way, up to a maximum size of 21x21. If one of the above conditions is not met then LxL is taken as the maximum stationary window, which is used for filtering pixel (i,j). Filtering is undertaken by simply averaging the pixels within that window. The normalized variance of averaged neighborhoods is also saved, since it contains information on the target type complementary to its mean value.

4. RESULTS AND DISCUSSION

Figs. 2a and 3a show different areas in Doñana marshes as captured by Envisat/ASAR on two different dates. The darkest area on the top right of Fig. 2a corresponds to an open water surface. On the opposite side, a watercourse runs through a shallow flooded bushland. Fig. 3a captures an area of vertically oriented helophytes emerging form the water.

Figs. 2c and 3c depict the same images, after applying the multi-resolution filtering method described in the previous section. These figures reveal the significant degree of smoothing achieved by the proposed method over land cover types of high variance texture, while edges among different covers are properly preserved.

Figs. 2d and 3d show the maximum stationary window size, used for computing the pixels' filtered values. They illustrate the adaptation of the processing window to the sharpness of the image structure, which is accomplished by means of the Ds multi-resolution thresholding.

Results of applying the enhanced Frost filter in 9x9 windows are included in Figs. 2b and 3b for comparison. This filter aims at removing just speckle noise. It implicitly assumes that intensity fluctuations due to speckle and terrain signal variations happen at very different spatial scales. Such assumption loses validity in areas of flooded vegetation: the accused increment in double bounce return due to moderate helophyte development, leads to high contrast radar returns in neighborhood pixels at comparable phenological stages. As a result, pixel intensities in areas of similar vegetation cover show contrasts not attributable only to speckle. The high CV in these areas is interpreted by Frost's and other locally stationary filters as indicative of edge presence and the filter impulse response is narrowed. As a result, significant intensity fluctuations remain, as it can be observed in Fig. 3b.

It has to be stressed that the presented filter does not aim at reconstructing the scene radar cross section as Frost's or Lee's filters do. The goal in the presented work was to smooth intensity fluctuations in highly textured areas corresponding to single cover types. The normalized variance of averaged neighborhoods is saved, since it contains information on the target type complementary to its mean value, and can assist a subsequent classification.

4. CONCLUSIONS

A new operator, Ds, has been proposed for local texture stationarity assessment on SAR images. The aim was to discriminate heterogeneous targets from land cover types exhibiting high normalized variance values. These situations can be confused by filtering method assuming stationary terrin RCS since both targets yield normalized variances greater than those expected from the image ENL.

Simulations of the confusion probability have shown similar edge sensitivity of Ds compared to that of the ratio edge detector or CV in presence of straight, sharp, centered boundaries, but significantly higher in the case of irregular or non-centered ones, which suggest that this operator is more appropriate for speckle filtering on SAR images of natural environments.

The use of Ds in a multi-resolution fashion for filtering Doñana marshes ASAR scenes has substantiated the usefulness of such operator. Maximum stationary texture windows were determined by Ds multi-resolution thresholding, and averaging was applied within them. Results reveal the important degree of smoothing achieved over cover types exhibiting high variance, while edges among different targets were properly preserved.

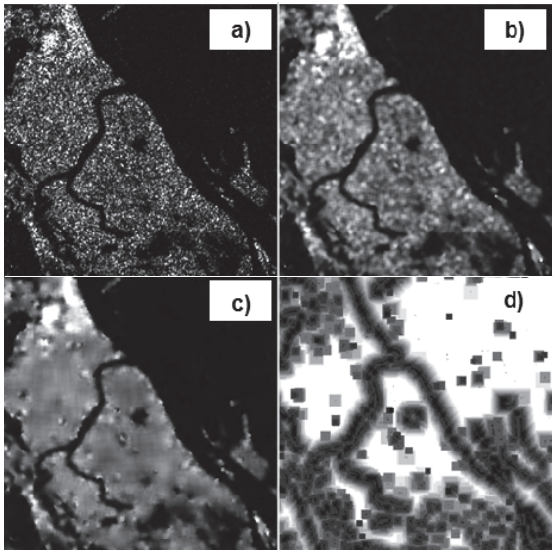

Fig. 2. Area in Doñana marshes captured by ASAR on 02 March 2007 at swath IS4, HH polarization, ENL=2.66**:** a) image calibrated to backscattering coefficient; b) image filtered with the enhanced Frost algorithm in 9x9 windows; c) image filtered by averaging maximum stationary windows; d) maximum stationary window size determined by Ds multi-resolution thresholding (from 1x1 in black to 21x21 in white).

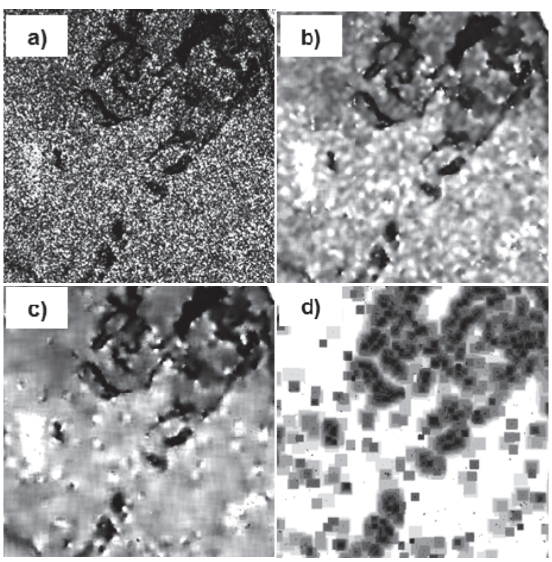

Fig. 3. Area in Doñana marshes captured by ASAR on 21 April 2007 at swath IS2, HH polarization, ENL=1.73**:** a) image calibrated to backscattering coefficient; b) image filtered with the enhanced Frost algorithm in 13x13 windows; c) image filtered by averaging maximum stationary windows; d) maximum stationary window size determined by Ds multi-resolution thresholding (from 1x1 in black to 21x21 in white).

5. ACKNOWLEDGEMENTS

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