Int. J. of Computers, Communications & Control, ISSN 1841-9836, E-ISSN 1841-9844
Vol. III (2008), Suppl. issue: Proceedings of ICCCC 2008, pp. 144-149

Statistical Edge Detectors Applied to SAR Images

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Abstract: Segmentation is a crucial step in automatic interpretation of images. However, the presence of speckle in Synthetic Aperture Radar (SAR) images makes their segmentation very difficult. Several methods of segmentation have been developed specifically to improve the interpretation of SAR images. In this paper, we present edge detectors applied to SAR images. First, we present the detector Ratio of Averages (ROA), which is based on the normalized ratio computation of intensity. But, this detector is optimum in the case of mono-edge. Second, we present the detector Ratio of Exponentially Weighted Averages (ROEWA), which is optimized for multi-edge model, in the Minimum Mean Square Error (MMSE) sense. Finally, we give experimental results of these operators on optical image, simulated SAR image and on ERS-1 SAR image.

Keywords: Edge Detection, Image Segmentation, Ratio of Average.

1 Introduction

Image segmentation is a fundamental step in image analysis. It consists of partitioning an image into homogeneous regions that share some common properties. There are two main approaches in image segmentation: edge- and region- based. Edge-based segmentation looks for discontinuities in the intensity of an image. Region-based segmentation looks for uniformity within a sub-region, based on a desired property, e.g. intensity, color, and texture. In this paper, segmentation by edge detection applied to ERS-1 SAR images is described. Edge detection plays a key role in image analysis. In images with no texture, an edge can be defined as the boundary between two regions with relatively distinct properties. The usual gradient-based edge detectors, developed for optical images, compute the difference between the local mean values on opposite sides of considered pixel.

In the last decade, Synthetic Aperture Radar (SAR) imaging systems have been widely used in the observation of the earth's surface. The main advantages of these systems are the ability to operate at any time of day, in any weather conditions, and to improve the image resolution for a given aperture size. The structures in SAR images give important contextual information useful to the detection and the classification of entities, as vegetation, urban area, and industrial area. However, because of the coherent nature of wave in radar, SAR images are degraded by specific noise called "speckle". The presence of speckle in SAR images makes their segmentation very difficult. In SAR images, the usual gradient-based edge detectors give more false edges in areas of high reflectivity than in areas of low reflectivity [2, 3]. Then, the presence of speckle in SAR images makes the usual edge detectors inefficient and complicates edge detection.

Several edge detectors have been developed specifically for SAR images [1, 2, 4, 5]. In this paper, we present the Ratio of Averages (ROA) operator based on the normalized ratio computation of local averages on opposite sides of the central pixel, for different directions and sizes of the analyzing window. However, this operator uses arithmetic means computed on opposite halves of the analyzing window. In this case, we consider only one edge is present in the analyzing window. This is only optimal in the idealized mono-edge case. The Ratio of Exponentially Weighted Averages (ROEWA) is an edge detector optimized for stochastic multi-edge model. It consists basically on the normalized ratio computation of means on opposite sides of the central pixel, with non-uniform weighting. The coefficients weighting of the pixels is considered as a function of the distance to the central pixel. In this case, several edges are considered present in the analyzing window.

2 Ratio of Averages (ROA) operator

The Ratio of averages (ROA) is an edge detector with Constant False Alarm Rate (CFAR), developed specifically for SAR images. In this operator, an analyzing window of size $N \times N$ is considered. This analyzing window is divided into two zones relative to central pixel. It calculates the ratio of arithmetic means $\bar{I}_1, \bar{I}_2$ of intensity on opposite halves of the analyzing window

$$r = \frac{\bar{I}_1}{\bar{I}_2} \tag{1}$$

On the analyzing window, we consider the presence of one edge only. Figure 2 illustrates the idealized mono-edge model in the horizontal direction. To make the operator independent of the scanning direction the ratio can be normalized. Both cases are present. The first one is based on the choice of the maximum ratio, than we obtain a ratio of intensity r greater than one. But, in this case the variation interval of the normalized ratio is not defined. The second one is based on the choice of the minimum ratio, this gives a limited interval. In this paper we consider the second case, and the ratio is normalized to lie between zero and one

$$r = \min\left\{\frac{\bar{I}_1}{\bar{I}_2}, \frac{\bar{I}_2}{\bar{I}_1}\right\} \tag{2}$$

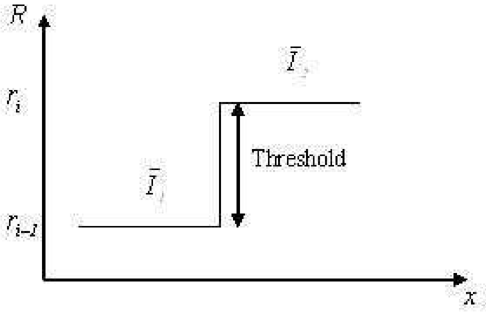

Figure 1: Unidirectional mono-edge model.

For each pixel, the ratio is calculated in different directions (horizontal, vertical, diagonals), and the minimum value of ratio is considered. A low and high ratio indicates respectively the presence of an edge and homogenous region. A pixel is affected to an edge if $r = \leq T(T$ is decision threshold of detection). Else, the pixel is affected to homogenous region. Then, the performance of the operator ROA depends on the choice of decision threshold T.

The performance of the operator ROA depends on the choice of decision threshold T. It is very important to know the conditional probability distribution of ROA $P_r(r/R_1, R_2, N_1, N_2)$ to fix the false alarm rate. The probability density of the ratio for Single Look image is given by [2]

$$P_r(r/R_1, R_2, N_1, N_2) = \frac{\Gamma(N_1 + N_2)\frac{1}{r}\left(\frac{N_1 r}{N_2 C}\right)^{N_1}}{\Gamma(N_1)\Gamma(N_2)\left(1 + \frac{N_1 r}{N_2 C}\right)^{N_1 + N_2}} \tag{3}$$

Where N_1, N_2 are the numbers of pixels in the two halves of the analyzing window. Figure 2 shows the conditional probability of ROA. In SAR image, the speckle is generally modeled as a strong multiplicative, Gamma-distributed random noise, with unity mean and variance equal to the inverse of the Equivalent Number of Independent Looks (ENIL) [3].

For a given decision threshold T and ratio contrast C, the probability of detecting an edge is:

$$P(T, C) = Prob(r > T/C) = \int_T^1 P(r/C)dr \tag{4}$$

Where $P(T, C)$ is the conditional probability of the normalized ratio.

The probability of false alarm (PFA) is the probability of detecting an edge in homogeneous region (the probability of detecting an edge in the case of the ratio contrast $C = 1$)

$$PFA(T) = P(T, 1) \tag{5}$$

Relation (5) permits to compute the value of threshold T, by fixing a low PFA and the ratio of contrast $C = 1$.

The performance of the ratio edge detector depends also on the choice of the analyzing window size (size of neighborhoods). The use of the small analyzing window permits to detect the micro-edges, but in this case the effect of the speckle is not reduced. The choice of large analyzing window gives a well reduction of speckle but

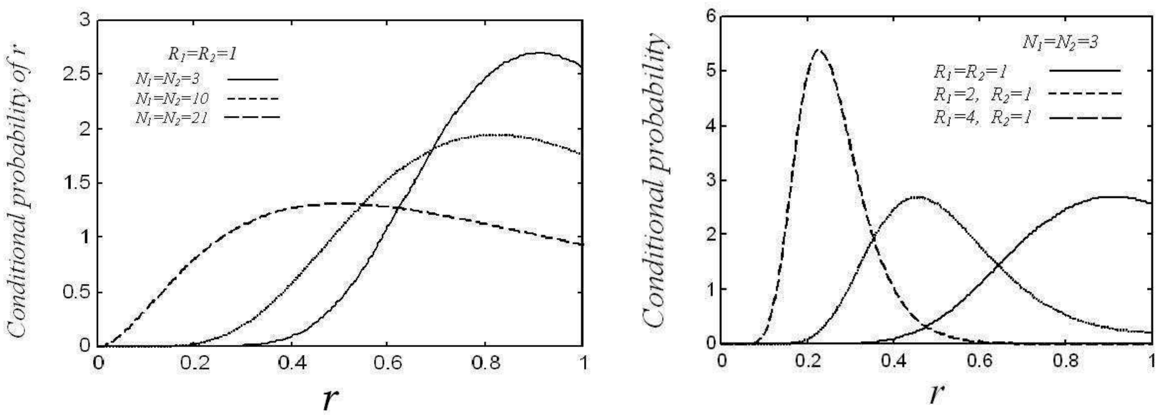

Figure 2: Conditional probability of ROA for different window sizes and reflectivity.

the micro-edges are not detected. In order to detect most edges and reduce the speckle, the ratio must be applied for different sizes of analyzing window. In our algorithm, we calculate the ratio on windows of increasing size from 3×3 to 9×9. The processes begin with computation of the ratio for the analyzing window of size 3×3. The computed ratio is compared to decision threshold and if an edge is detected we pass to the next pixel, else the ratio is computed for an analyzing window of size 5×5. We test the ratio and if an edge is not detected we pass to a window of size 7×7.The same operation is applied for each analyzing window. The process is stopped for a window size of 9×9, and if an edge is not detected for this window the considered pixel is assigned to homogenous region. To detect more edges the ROA detector is applied for all possible directions (the four usual directions are: horizontal, vertical, diagonal 1, diagonal 2). The ratio is computed for each direction and the minimum value corresponds to the direction of the most probable edge. The PFA for the ratio computed in four directions is given by [2]

$$PFA_4 = 1 - (1 - PFA_1)^3 \tag{6}$$

Where PFA_1 is the PFA of the ratio computed in one direction.

3 Ratio Of Exponentially Weighted Averages operator (ROEWA)

To reduce the influence of the speckle sufficiently, the analyzing window size must be important. A large window can contain several edges simultaneously. There is a conflict between speckle reduction and high spatial resolution. An edge detector based on multi-edge model, which is optimal in the Minimum Mean Square Error (MMSE) sense, is applied to SAR images to improve the speckle suppression and edge detection properties. Basically, it consists on the means ratio computation on opposite sides of the central pixel, with non-uniform weighting. The pixels coefficients weighting are considered as a function of the distance to the central pixel. In the case of multi-edge detector, several edges are considered in the analyzing window, Figure 3 presents the multi-edge model in one direction.

We suppose that SAR image is composed by zones of constant reflectivity. In the horizontal direction or in the vertical direction, the reflectivity R is a random process composed by segments of reflectivity, with mean μ_r and deviation σ_r. The change of reflectivity follows a Poisson distribution. That, the probability to have n jumps in the interval $\triangle x$ is given by

$$P(n/\triangle x) = \frac{(\lambda_x \triangle x)^n}{n!} e^{-\lambda_x \triangle x} \tag{7}$$

Where λ_x is the mean jump frequency.

The optimum impulse response in horizontal direction is obtained by minimizing the mean square error of reflectivity

$$f(x) = Ce^{-\alpha|x|} \tag{8}$$

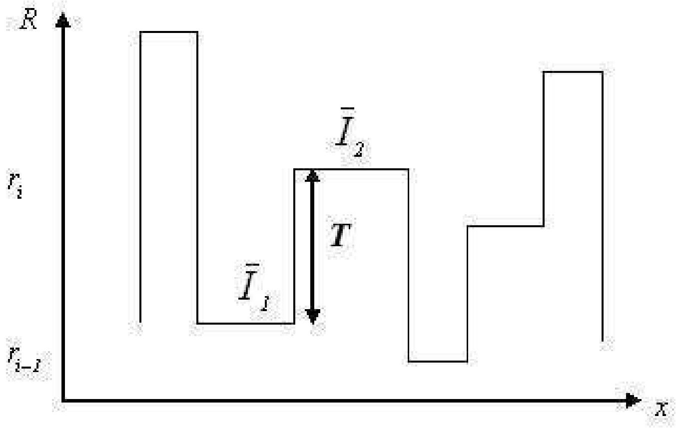

Figure 3: Unidirectional multi-edge model.

where

$$\alpha = \frac{2L\lambda_x}{1+(\mu./\sigma.)^2} + \lambda_x^2 \tag{9}$$

Figure 4 illustrates the optimum impulse response in the horizontal direction.

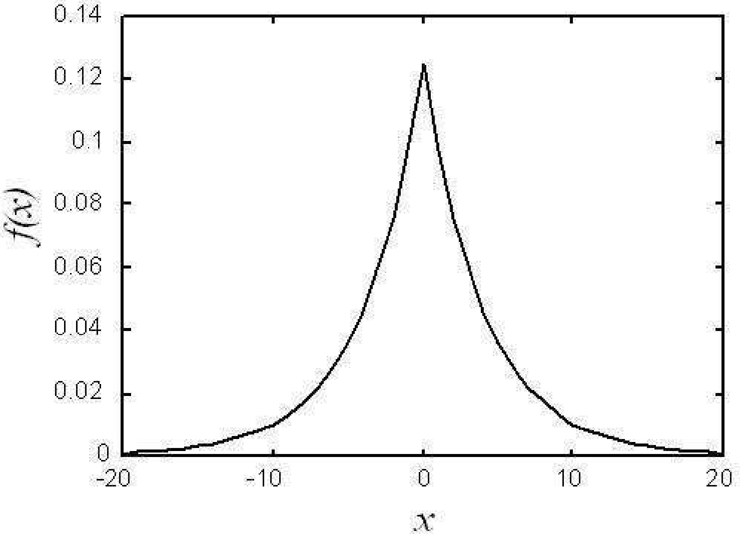

Figure 4: The impulse response of the exponential filter in horizontal direction ($\alpha = 0.25$).

In the discrete case, the filter $f(x)$ can be implemented very efficiently by pair of filters (causal and anti-causal). To detect the horizontal edge, the image is first smoothed column by column using the filter $f(x)$. Next, the means on the two opposite sides of each pixel are computed line by line independently, using the two filters causal and anti-causal. The means ratio obtained is calculated for each pixel. The ratio is normalized to lie between zero and one by taking the minimum of the ratio computed and it's inverse. The ratio in the vertical direction is computed by the same manner. The performance of this operator depends on the parameter choice α of the exponential function. The ROEWA is computed only for two directions (horizontal, vertical), the minimum of ratio indicates the presence of an edge. The ratio is compared to decision threshold, but in this case it is difficult to calculate the PFA correspond to the decision threshold.

4 Results

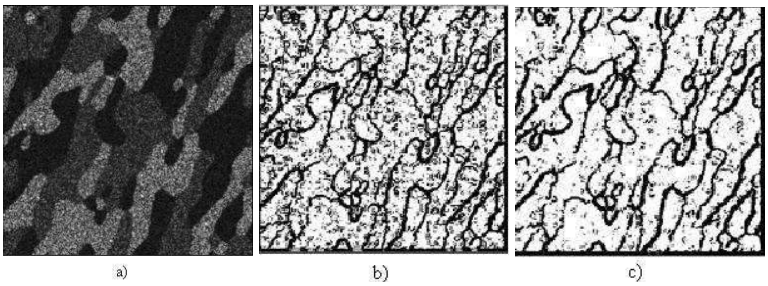

Figure 5: Edge detection of simulated image (a) speckled simulated Image (b) ROA Edge detection (c) ROEWA Edge detection

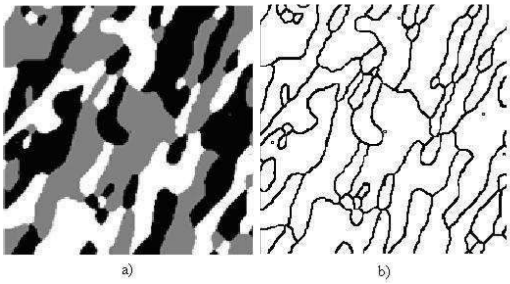

Figure 6: Edge detection of simulated image (a) simulated Image without speckle (b) ROA Edge detection

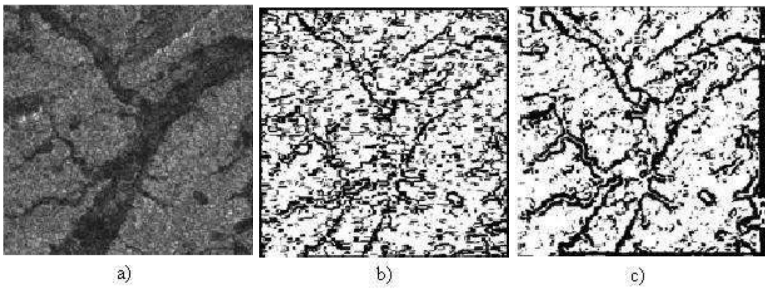

Figure 7: Edge detection of SAR image (a) ERS-1 SAR image (b) ROA Edge detection (c) ROEWA Edge detection.

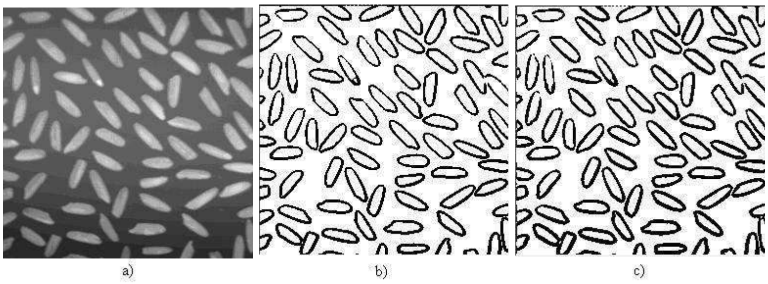

Figure 8: Edge detection of optical image (a) Optical image (b) ROA Edge detection (c) ROEWA Edge detection.

5 Conclusion

In this paper, two edge detectors are presented. These detectors are applied to simulated SAR images, and to real data of ERS-1 SAR image. The ROA operator gives best results than the usual gradient-based edge detectors. But, it is optimum only for mono-edge case. The performance of ROA depends on the choice of window size and on the decision threshold. The performance of this detector can be improved by working on different resolution. Each resolution corresponds to certain size window. The ratio is computed for different window sizes. The small window size permits to detect the micro-edges, and the large window permits a reduction of speckle. The ROEWA operator is a detector optimized for multi-edge model. The results obtained with the ROEWA detector is better than results obtained with ROA detector, when they applied to simulated SAR image and ERS-1 SAR image. The ROA and the ROEWA detectors permit to improve the edge detection in SAR images. Also, these detectors give best results when they are applied to optical images.

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