# SAR Image Edge Detection by Ratio-based Harris Method

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**ABSTRACT**

The presence of speckle, which modeled as a strong multiplicative noise, makes the edge detection of synthetic aperture radar (SAR) images very difficult. The usual edge detectors using gradient yield poor results. By analyzing Harris' combined corner and edge detector, to solve the speckle-sensitivity and anisotropic response, an edge detection method used for SAR image is presented. Horizontal, vertical and diagonal ratios of averages of non-overlapped neighboring pixel values instead of gradients are used to calculate edge strength maps (ESM); then they are fused to obtain the final ESM; finally, a threshold is presented to obtain edge detection result. Analysis and experiment results illustrate that the proposed method can be used for edge detection in SAR image effectively.

## 1. INTRODUCTION

Since edges are primitive image features useful in determining the physical extent of image objects, edge detection is important in the processing of SAR images for further segmentation, classification, and image registration. Due to the coherent nature of the illumination, radar images are speckled. The usual edge detectors, successful with incoherent images, yield poor results when applied to radar image directly, especially those with a small number of looks. Their performance degrades seriously because they are very sensitive to the speckle noise.

Intuitively, an edge is a set of connected pixels that lie on the boundary between two regions. A lot of algorithms use first-order or second-order derivatives to detect the presence of an edge at a point in an image, such as Roberts, Prewitt, Sobel, LoG and Canny. In fact, the fundamental of these algorithms is to find intensity variation over local neighborhoods. They fail in processing SAR images because they often rely on the assumption that the noise is white additive and Gaussian; this is never verified in radar imagery, in which the noise is multiplicative. In the case of SAR images, local edge or line detectors are often based on statistical properties or on the intensity ratio of neighboring regions [2-4].

Harris and Stephens proposed a combined corner and edge detector [1]. It estimates the measure of local autocorrelation using first-order derivatives which is suggested by performing an analytic expansion of the Moravec operator. The response is theoretically isotropic as the variation of the autocorrelation over different orientations can be calculated from the principle curvatures of the local autocorrelation. In SAR image, Harris is too sensitive to speckle and produces variable false-alarm rate edge response caused by using gradient and anisotropic response caused by using only horizontal and vertical gradients when implemented. By solving these problems, an improved edge detector using ratio-based technology is proposed in this paper. Analysis and experiment results illustrate that the algorithm can be used for edge detection in SAR image effectively.

This paper is organized as follows: Section 2 briefly revisits the combined corner and edge detector proposed by Harris and Stephens; Section 3 analyses the problems for Harris edge detector used for SAR images and propose the corresponding solution for them; the experiments on a simulated image and real SAR images are presented in the end.

## 2. HARRIS REVISITED

Harris operator considers a local window in the image and determines the average change of intensity resulting from shifting the window by a small amount in various directions. Three cases are considered for shifts:

1) In flat region, there is only a small variation in all directions;
2) On the edge, there is a small variation along the edge direction, but a large variation perpendicular to the edge;
3) At the corner or isolated point, there is significant variation in all directions.

Mathematically, the intensity variation $E$ produced by a shift $(u, v)$ is given by:

$$E(u,v)=\sum_{x,y} w(x,y)\left[I(x+u,y+v)-I(x,y)\right]^2 \qquad (1)$$

where $I$ is the image intensity and $w(x,y)$ is a Gaussian window function.

By performing Tayler expansion about the shift origin and approximating the first gradients, for a small shift ($u$, $v$), $E(u,v)$ can be written

$$E(u,v) \approx Au^2 + 2Cuv + Bv^2 \tag{2}$$

Hence, the intensity variation can be measured in any direction. Furthermore, equation (2) can be written in matrix form

$$E(u,v) \approx (u,v)M(u,v)^T \tag{3}$$

where $M$ is a 2×2 symmetric matrix computed from image gradients.

$$M = \sum_{x,y} w(x,y) \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} = \begin{bmatrix} A & C \\ C & B \end{bmatrix} \tag{4}$$

$E(u,v)$ is closely related to the local autocorrelation function, with $M$ describing its shape at the origin. Matrix $M$, which can be called as *local structure matrix*, contains all differential operators describing the geometry of the image surface at a given point ($x$, $y$). Eigenvalues of matrix $M$ are proportional to the principle curvatures of the image surface, and the relationship and magnitude of the eigenvalues $\lambda_1$ and $\lambda_2$ describe three distinguishable feature regions.

Harris and Stephens propose the following measure at the position ($x$, $y$)

$$R = Det(M) - k \cdot Tr^2(M) \tag{5}$$

where $Tr(M) = \lambda_1 + \lambda_2 = A + B$ , $Det(M) = \lambda_1 \cdot \lambda_2 = AB - C^2$ and $k$ is a empirical constant. $R$ is positive in the *corner region*, negative in the *edge regions*, and small in the *flat region* [1], as shown in Fig. 1.

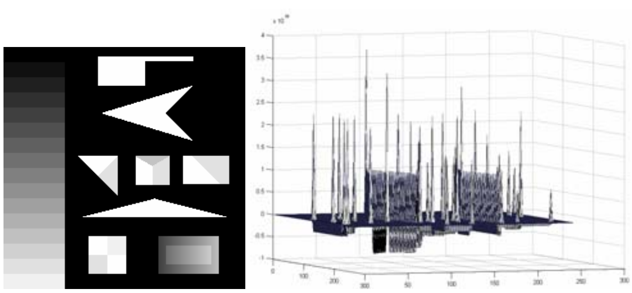


**Fig. 1.** Strength map of Harris measure for test image ($k$=0.04)

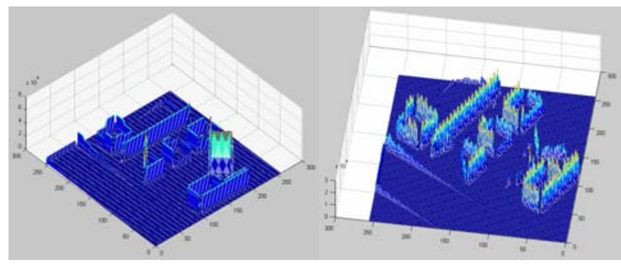
## 3. RATIO-BASED HARRIS EDGE DETECTOR

It can be noticed from the revisit that the fundamental idea of the Harris edge detector is to find and determine intensity variation locally. In practice, the algorithm uses image gradients to calculate the intensity variation of the image (that is, elements of $M$ are calculated using only the horizontal and vertical gradients).

$$I_x = \frac{\partial I}{\partial x} = I \otimes (-1,0,1), \quad I_y = \frac{\partial I}{\partial y} = I \otimes (-1,0,1)^T \tag{6}$$

Since any algorithms using gradient are somehow noise dependant, Harris uses a circular Gaussian window function $w(x,y)$ to overcome noisy responses.

The first problem for using Harris edge detector is that the speckle in SAR image is not white additive and Gaussian. Speckle is a determinist phenomenon common to all imaging systems relying on coherent illumination. The constructive and destructive interferences of backscattered waves of the elementary scatterers within a resolution cell yield important variations in the observed intensity. At the image scale, the speckle appears as a strong granularity that makes automatic analysis very difficult. In SAR image, the speckle is modeled as a Gamma distributed multiplicative noise of mean one and variance equal at the inverse of the equivalent number of looks [5]. From the analysis in [2], it can be noted that, within a homogeneous area, the larger the mean power is, the larger the gradient PDF will be. So if we apply a gradient operator based on the difference of averages on a SAR image, we detect more false edges in high reflectivity areas than in low reflectivity areas.



(a) (b)

**Fig. 2.** Simulate images' ESMs. (a) is the ESM of original image and (b) is the ESM of image rotated 30° of Fig. 1(a)

In order to overcome the problem mentioned above, we measure intensity variation using the ratio of averages (RoA) of each side of the interested pixel instead of using gradients. Ratios of averages calculated over local neighborhoods give a constant false-alarm rate (that is, the rate of false alarms is independent of the average radiometry of the considered region). This operator coincides with the likelihood rate (LR) operator [6] when the analyzing window is split into two parts of equal size.

The second problem is that, matrix $M$ is indeed rotational invariant from the point of mathematical, but the elements of $M$ are calculated using only the horizontal and vertical gradients, there is an anisotropic edge response. Fig. 2 shows the edge strength maps (ESM) of the simulate image and its rotated 30° version. Noticed that compared with the ESM of the original test image, the ESM of the rotated image is not flat on the top of the edge position, and the strength amplitude is smaller.

To overcome the second problem, we use ratios of averages instead of horizontal and vertical gradients. As shown in Fig. 3, there are four direction ratios of averages denoted as horizontal, vertical, main diagonal and auxiliary diagonal. It must be point out that the definition of the directions of RoA is different from those in [2], because the purpose of using RoA in this paper is to detect homogenous in the given direction, not the edge direction at the interested point.

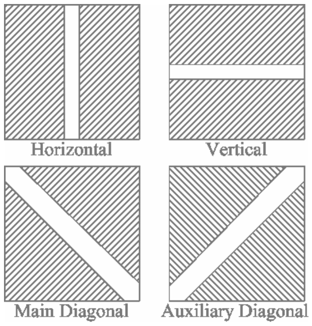



**Fig. 1.** Four directions of RoA for intensity variation detection

In our method, we use $I_h$ and $I_v$ in place of $I_x$ and $I_y$ to get an ESM of the image, and use $I_{md}$ and $I_{ad}$ in place of $I_x$ and $I_y$ to calculate another ESM, and then fuse them in order to get an isotropic response.

The problem here is how to fuse these two ESMs. The very core of the RoA is detecting homogeneous of two non-overlapped neighboring regions in radar image using a CFAR operator. Obviously, the ratio of the averages is equal to one when the two regions are homogeneous. Hence, the minimizing (towards zero) of the two ESMs can be easily chosen as the fusion method. That is

$$ESM = \min(ESM_{h,v}, ESM_{md,ad}) \tag{7}$$

Fig. 4 shows the fused ESM of the rotated image. Compared with Fig. 2(b), it can be seen that the edge responses of our method is better.

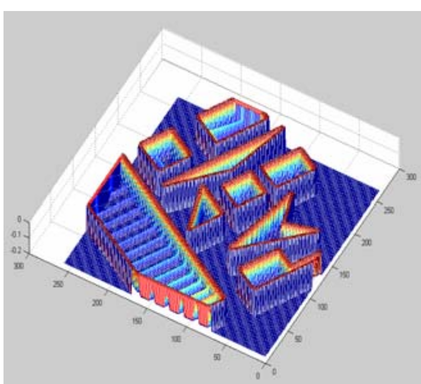


**Fig. 2.** Edge strength map of the fusion result

Briefly, the steps of the proposed method can be summarized as following:

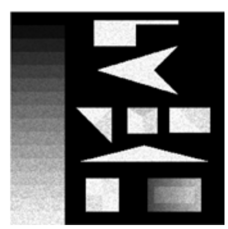
1) Convolve the image with four $m\times m$-pixel masks to obtain $I_h$, $I_v$, $I_{md}$ and $I_{ad}$;
2) Calculate local structure matrix $M$ using $I_h$ *and* $I_v$, $I_{md}$ and $I_{ad}$ in place of $I_x$ and $I_y$ separately;
3) Obtain two ESMs by computing equation (6);
4) Fuse the two ESMs to produce a final ESM;
5) Specify a threshold $T$ to obtain the edge detection result.

## 4. EXPERIMENT RESULTS

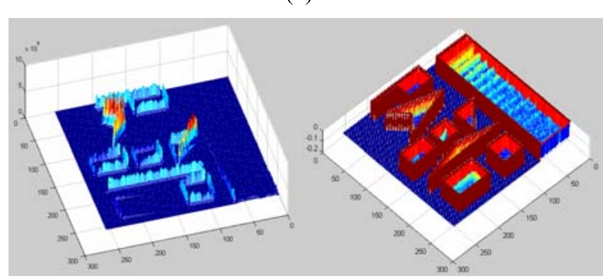
The method has been tested on a variety of test images including a simulated speckled image and real SAR images. A simulated image is shown in Fig. 5(a) which has speckle noise with variance 0.01. Fig. 5(b) and (c) present the ESM of (a) obtained by using Harris method and using the proposed method. It can be noticed that the proposed method produces smoother and stronger edge responses.

Experiment results on real SAR images are shown in Fig. 6 and Fig. 7. In both the experiments, threshold $T$ is choosen as about 10% of the minimum of the ESM. Fig. 6(a) is a SAR image whose equivalent number of look is 3，Fig. 6(b) is the result by using our method with 5x5-pixel mask and threshold $T = -0.02$, Fig. 6(c) is the result by using Canny with automatically chosen thresh and $\sigma = 1$, Fig. 6(d) is the result by using ratio edge detector in [2] with threshold 0.7160 which is calculated by setting probability of false alarm rate as 1%.

Fig. 7(a) is a SAR image whose equivalent number of look is 2, and this image has much more notable speckle noise. Fig. 7(b) is the result by using our method with 5x5-pixel mask and threshold $T = -0.02$, Fig. 7(c) is the result by using Canny with automatically chosen threshold and $\sigma = 1$, Fig. 7(d) is the result by using ratio edge detector with threshold 0.6620 which is calculated by setting probability of false alarm rate as 1%.

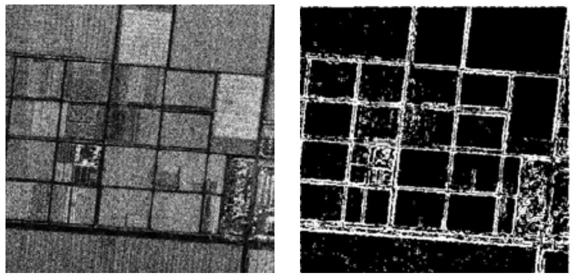


(a)

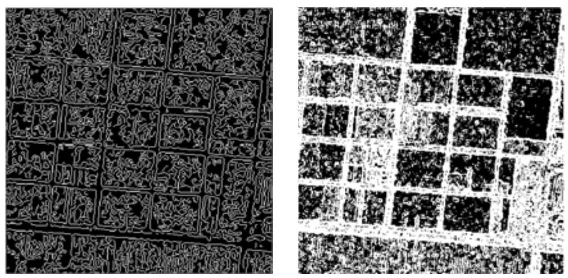


(b) (c)

**Fig. 3.** Edge strength map of simulated speckled image (see text)

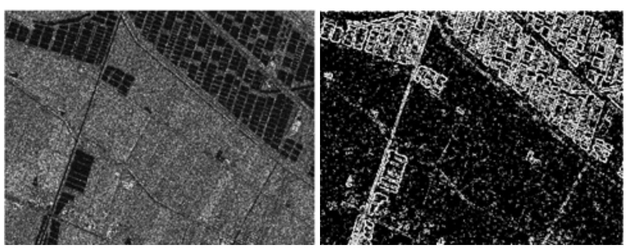


(a) (b)

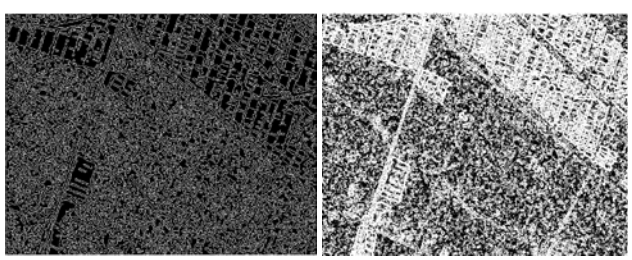


(c) (d)

**Fig. 4**. SAR image and edge detection result (see text)



(a) (b)



(c) (d)

**Fig. 5**. SAR image and edge detection result (See text)

## 5. CONCLUSION

In this paper, we have analyzed the problems for Harris' algorithm used in SAR images and proposed the corresponding solution. This is confirmed by experiment results with the ratio-based improved Harris edge detector. The method gives improved edge detection results over the Canny and MRoA methods, and has been shown to generate good edge maps for both simulated speckled image and satellite SAR images.

In future work, we need to carry out edge hysteresis by applying low and high thresholds to produce thin and continuous edge map. By considering the homogeneous directions, the orientation information may be used to advantage in improving the detection of edges in speckled images.

**Acknowledgements**: *The research work in this paper is sponsored by the National Key Fundamental Research & Development Programs of P. R. China, No. 2001CB309403.*

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