An Edge Detection Operator for SAR Images

Gary Geling, and Dan Ionescu
Department of Electrical Engineering, University of Ottawa
Ottawa, Ontario,Canada

Abstract: The detection of small linear features from SAR imagery is complicated by the presence of speckle and the non-stationarity of the image data. A feature detector is derived from the contrast ratio edge detector to extract linear features from SAR imagery with a constant probability of false alarm. The output of the feature detector is then passed through a thresholded grey level closure operator to thin the detected features, connect adjacent linear features, and remove isolated noise points and linear fragments. The resulting operators are applied to ERS-1 images to illustrate their effectiveness.

Field :Computers; Image Processing; Remote Sensing

INTRODUCTION

Synthetic aperture radar (SAR) images are used for many applications such as ship detection, and coastline detection that are dependent on locating linear features [1],[2]. Features such as roads, rivers, and trailing edges of woodland often show up as darker thin features and railways, hedges and leading edges of woodland will show up as brighter thin features. A feature extraction operation encounters many difficulties due to the high level of noise and the poor quality of the object contour which may change with meteorological conditions or aspect angle [3]. A method for extracting the contours of the linear features must take into account the high noise level associated with SAR and its multiplicative nature.

There has recently been a number of constant rate of false alarm edge detectors for SAR imagery developed as summarized in [5] and [6]. The combination of an edge detector based on the contrast ratio with the concept of anti-parallel lines [8] has been used to develop a linear feature detector with a low probability of false alarm, P_{fa} .

IMAGE MODEL

SAR imagery is subject to multiplicative noise in the form of speckle due to the coherent nature of radar. It has been shown [4] that for areas of fully developed speckle, the probability density function of the irradiance is a negative exponential. The contrast ratio [6],[7], has been proven to be useful as an edge detector for SAR imagery. The resulting detector has the advantage of having a deterministic means of calculating a threshold for a desired constant P_{fa} over the entire image.

FEATURE EXTRACTION OPERATOR

A linear feature is defined as a contiguous region of width w, and length l, that is surrounded along its sides by contiguous regions. The extraction of linear features is interpreted in [8] as the detection of "anti-parallel" line segments. For small linear features, the determination of anti-parallel line segments can be found using a combined operator. A $n \times n$ window can be divided into three linear, parallel neighbourhoods; A_1, A_2, and C, each consisting of N independent samples. They are arranged such that C is in the centre. The probability that a given neighbourhood is part of a linear feature may be expressed as a function of the two ratios A_1/C and A_2/C.

The assumption of the independence of the N samples within each neighbourhood was shown to be incorrect in [7]. It was pointed out that many SAR images have auto-correlation functions indicating inter-pixel correlation and that ERS-1 images showed a correlation of approximately two pixels in range and in azimuth. This effects the choice of the threshold for non-corrected images when selecting for a given P_{fa} .

It was concluded in [6] that the standard contrast ratio operator was not adapted to thin linear boundaries. This may have been due to the inter-pixel correlation in the radar image. In order to improve the detection of such linear features, the contrast ratio function is bounded. A threshold ratio value, T_1, is selected so that the P_d is very nearly one and the P_{fa} is very low as well. This threshold value is used to bound the response of the operator to prevent saturation by steep one-sided gradients that, although edges, are not the linear features that are to be detected. This also has the effect of keeping the result bound to a range over which it is simpler to keep the thresholding step well-conditioned.

The filter is also designed to reject regions where the behaviour of the image is not consistent with a homogeneous linear feature. An indicator of along line change is used to determine the fitness of the neighbourhoods as a line candidate. The contrast ratio of the image along the C neighbourhood is calculated over sub-neighbourhoods of C. A second threshold, T_2, is selected to specify the amount of along line variation that is acceptable. This threshold should be chosen so the P_d for this value is relatively low.

The combination of these functions parallels the development of the Duda road operator [9] and will be referred to as the multiplicative Duda operator.

The final form of the linear feature extraction operator for darker features is of the form

$$R_1 = \frac{\sum_{i=1}^{N} C_i}{\sum_{i=1}^{N} A_{1i}}$$

$$R_2 = \frac{\sum_{i=1}^{N} C_i}{\sum_{i=1}^{N} A_{2i}}$$

$$F_i(x) = \begin{cases} 1 & \text{if } R_i > 1 \\ R_i & \text{if } T_1 < R_i \leq 1 \\ 0 & \text{otherwise} \end{cases}$$

$$R_c = \frac{\sum_{i=1}^{(N-1)/2} C_i}{\sum_{i=(N+1)/2}^{N} C_i}$$

$$R_a = \min(R_a, 1/R_a)$$

$$G(x) = \begin{cases} 1 & \text{if } R_a > T_2 \\ R_a/T_2 & \text{otherwise} \end{cases}$$

$$H(x) = (1 - F_1(x))(1 - F_2(x))(G(x)) \quad (1)$$

The operator for bright features uses the inverted values of

R_1 and R_2. Four templates were chosen for the 5×5 operator. Two of the neighbourhood templates chosen for a 5×5 window are given in Figure 1. The other two are a 90° rotation of the two given.

A		C		B
A		C		B
A		C		B
A		C		B
A		C		B

	A	A		C
A	A		C	
A		C		B
	C		B	B
C		B	B	

Figure 1: 5×5 Neighbourhood Templates

FEATURE EXTRACTION

A simple thresholding of the output of the multiplicative Duda operator leaves many unconnected line segments. As well, there are some noise points and a number of features that are too short to be of use in detecting larger structures within the image. The operator also has a number of returns that are centred about the thresholded lines that should be pruned. A thresholded grey level closure operator is used to thin detected linear features, connect nearby features via a low cost path, and remove isolated noise points and linear fragments.

RESULTS

The 5×5 Duda-like operator is applied in four directions to a 512×512 6-look ERS-1 image of the Ottawa area supplied by CCRS. The original image is shown in Figure 2. The mDuda operator is applied to the SAR image with a threshold ratio, T_1, of 5. The along line threshold, T_2 was set at 2. The result is normalized to a byte image. The grey-level closure is then applied with an upper threshold of 70 and a lower threshold of 45. The simple threshold using the upper threshold is shown in Figure 3 and the output of the complete grey level closure operation is shown in Figure 4. The final results after the removal of isolated noise and small linear fragments is given in Figure 5

The output of the mDuda operator appears noisy and contains many "thick" features where there are stong line segment indicators. The grey-level closure operator is very efficient in thinning these strong returns to the path of the local maximum values. Many of the line segments are connected by the grey closure, but there remain a great number of isolated line fragments that must be removed by the segment size threshold. From the results in Figure 5 it is seen that many linear features remained unconnected even after the grey scale closure. In some cases this may be remedied by applying the operator at different scales. The output of the detector is directly overlayed over the original image and is shown in Figure 6. This illustrates the the excellent response in regions of high contrast. Areas of high texture such as the region of grassland around the airport and the agricultural areas also show many returns that may be due to the texture and not actual linear structures.

6. CONCLUSIONS

The multiplicative Duda operator is capable of detecting fine linear features in SAR images. There are many areas that are disconnected. This may be solved through the use of operators of different sizes, but the operator will still suffer many of the same problems as the original Duda operator in that it is less sensitive to diagonal and off-diagonal line segments, and that it rejects areas where line segments intersect. Although operators of other sizes could be generated, as the size increases so does the complexity. Four directional templates would not be suffi-

Figure 2: Original ERS-1 SAR Image

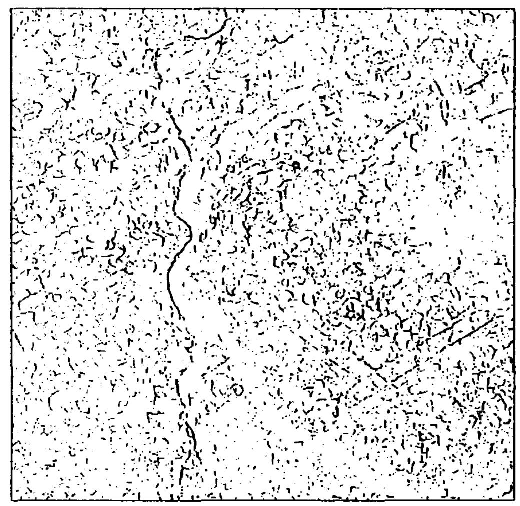

Figure 3: Thresholded Image after mDuda, $T_1 = 5$, $T_2 = 2$, Threshold=70.

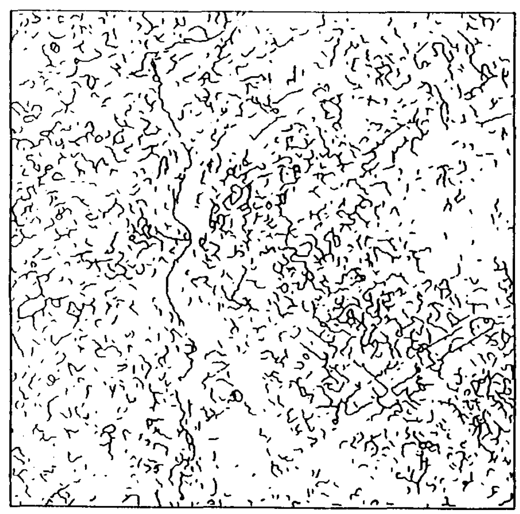

Figure 4: Grey Level Closed Image, $T_{upper} = 70$, $T_{lower} = 45$.

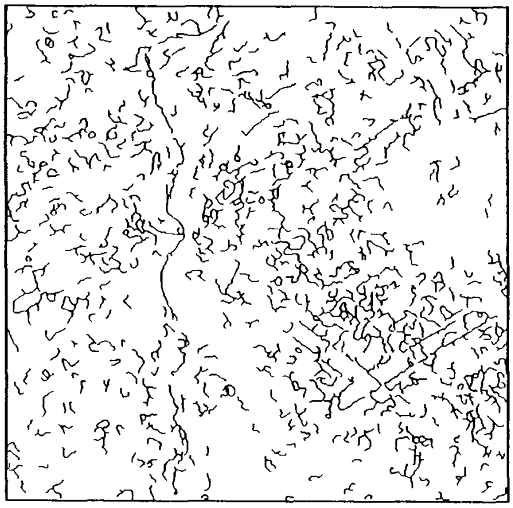

Figure 5: Output after Isolated Segments Removed, Minimum Segment Size = 10 pixels.

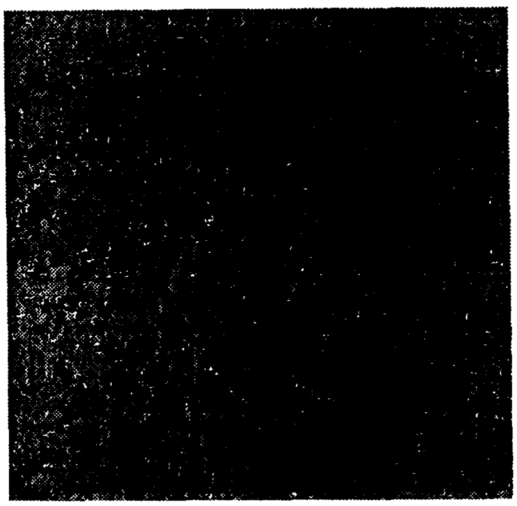

Figure 6: Overlay of Detected Linear Features with Original Image.

cient for a 7×7 window, and especially not for windows of larger sizes. It seems that it will also be necessary to modify the filter so that it is adaptive based on more global conditions such as texture. The response in built up areas offers high contrast and easier detection of linear features. These features are also more likely to correspond to physical structures such as runways, highways, and railways. In highly textured areas, the linear features detected may be the results of the random texture fields of the imaged region resulting in many small disjoint line segments. Using the same thresholds in each region would preclude detection in some areas in order to reduce random response in others. Overall, this method seems promising in detecting fine linear features.

References

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