AN EDGE-ENHANCED MODIFIED LEE FILTER FOR THE SMOOTHING OF SAR IMAGE SPECKLE NOISE

C. Ju and C. Moloney

Faculty of Engineering and Applied Science
Memorial University of Newfoundland
St. John's, NF, Canada A1B 3X5
E-mail: {ju,moloney}@engr.mun.ca

ABSTRACT

One problem in processing Synthetic Aperture Radar (SAR) images is the presence of speckle noise which is multiplicative in the sense that the noise level increases with the magnitude of radar backscattering. In this paper, an edge-enhanced filtering method is presented which is based on a ratio-based edge detector used in conjunction with an iterative application of a modified Lee filter. Test results obtained by applying this method to synthetic images corrupted by SAR speckle show that the edge-enhanced modified Lee filter has the ability to remove speckle in both low and high variance regions while retaining the sharpness of edges even after several iterations. As such, this filtering method may be useful in SAR image segmentation and classification applications.

1. INTRODUCTION

The speckle noise in Synthetic Aperture Radar (SAR) images can hinder the ability of computer vision algorithms to locate and recognize image detail. The reduction of speckle is therefore a fundamental first step in processing SAR data in many image processing and analysis applications. Since speckle noise is nonadditively combined with the underlying image, researchers have developed various nonlinear filtering techniques which seek to reduce the effect of speckle noise while preserving the informative structure of the underlying image (e.g. [1–3,5–9] and others). One such well-known SAR smoothing filter is the locally adaptive Lee multiplicative filter [1] and its variations (e.g. [2, 3]), which are quite effective in removing speckle especially in homogeneous or low variance areas. In high variance areas, however, the filter's parameters are adjusted to preserve edges; this has the effect of also preserving speckle noise near and on edges.

In this paper, an edge-enhanced filtering method is presented which is based on edge information obtained from the ratio-based MSPRoA edge detector [4] used in an iterative application of a modified Lee filter. The modified Lee filter differs from the original Lee filter in its definition of the local areas used to determine the filter's parameters; only those neighbourhood pixels which do not belong to edges and which appear to belong to the same image region are included in the calculation of local statistics. Moreover, at each iteration the ratio of the standard deviation to mean in homogeneous areas, a measure of the speckle noise remaining in the image, is automatically estimated from the image by a method proposed in [5] and used to control the filtering of that iteration. The overall process tends to remove the speckle in high variance regions while retaining the sharpness of edges even after several iterations.

2. LEE'S MULTIPLICATIVE FILTERS

2.1. Lee multiplicative filter

The Lee multiplicative filter [1] is based on a multiplicative noise image model:

$$z_{i,j} = x_{i,j} \cdot v_{i,j} \tag{1}$$

where z, x and v denote the observed image, underlying image and noise processes, respectively. Based on an assumption that the noise is white with unity mean and uncorrelated with the image x, the multiplicative Lee filter seeks the best mean-squared estimate $\hat{x}$ of x. At each pixel $z_{i,j}$,

$$\hat{x}_{i,j} = \bar{x} + k_{i,j}\,(z_{i,j} - \bar{x}) \tag{2}$$

This research is supported in part by a grant from the Natural Sciences and Engineering Research Council (NSERC) of Canada

where the gain factor $k_{i,j}$ can be obtained as

$$k_{i,j} = \frac{\text{Var}(x)}{\bar{x}^2\,\sigma_v^2 + \text{Var}(x)} \tag{3}$$

The local adaptation of the filter is based on the calculation of the local statistics, $\bar{x}$ and Var(x) from the data sample estimates $\bar{z}$ and Var(z) determined over a local neighbourhood window.

By adapting its parameters to both low-variance areas and high-variance areas, the filter both smooths noise and preserves edges. In order to preserve edges, the filter essentially shuts itself off in high variance areas (i.e. $k_{i,j} \approx 1$) so that the estimate $\hat{x}_{i,j}$ is approximately equal to the observed pixel value $z_{i,j}$.

2.2. Refined Lee multiplicative filter

To improve the performance in edge areas, Lee proposed a refinement to the original Lee multiplicative filter [2], in which the neighbourhood used in high variance areas for the calculation of the local statistics takes into account the orientation of a possible edge. For each pixel with local variance Var(z) exceeding a set threshold, oriented gradients are computed and used to select a subset of the neighbourhood pixels on one side of the edge and most like the central pixel. Var(z) estimated over this subset will in general be lower than the sample variance over the whole neighbourhood, allowing more accurate filtering of noise. However, the edge detection is not optimized for speckle corrupted images in which local variance is related not only to edges but also to the underlying mean intensity level.

2.3. Iterative Lee multiplicative filter

For segmentation purposes, Lee and Jurkevich [3] proposed a scheme based on an iterative application of the Lee multiplicative filter. Several iterations of the Lee multiplicative filter can greatly reduce speckle noise. However, small details may be lost due to the repetitive smoothing operation; and, as with the one-pass Lee filter, speckle noise is preserved in edge areas.

2.4. Estimation of Coefficient of Variation

The Lee multiplicative filters require the knowledge of the ratio of the standard deviation to mean in homogeneous areas. This parameter is seen to be σ_v for unity mean noise, and is sometimes called the Coefficient of Variation (CoV). This value can be estimated by calculating $\sigma_z/\bar{z}$ over several homogeneous or structure free areas of the observed image z. Moreover, the initial value of the parameter σ_v can be determined from the known speckle characteristics of the number of looks and type of SAR image to be filtered (e.g. see [1, 3]).

However, the application of a nonlinear filter can significantly alter the noise characteristics, and it can be difficult to analytically update the parameter σ_v in an iterative filtering scheme. In this research, σ_v is automatically estimated from the image data by a method proposed in [5], thus better controlling the filtering process for each pass of the filter. The entire image is partitioned into equal sized windows (e.g. 7×7) and σ_v calculated in each window. Then, the histogram of these local estimates is obtained, and the histogram mode is taken as an overall estimate of σ_v. For moderately busy images, the use of the histogram mode tends to highlight the local estimates of σ_v in the homogeneous regions, and to exclude those erroneous estimates of σ_v in areas of high variance such as edge regions.

3. RATIO-BASED EDGE DETECTOR

Ratio-based edge detectors estimate edge strength at any pixel of interest in an image by calculating the ratio between neighbouring pixel values. The Maximum Strength Edge Pruned Ratio of Averages (MSP-RoA) method developed in [4], is one such method which has been shown to provide accurate localized edge maps from speckled SAR images. At each pixel in the image, the method calculates the four ratio edge strengths

$$R_i = \min(P_i/Q_i, Q_i/P_i), \quad i = 1, 2, 3, 4 \tag{4}$$

corresponding to the four usual orientations, as illustrated in Figure 1, where P_i and Q_i are the averages calculated over the sub-windows denoted P and Q, respectively. The MSP-RoA then calculates a vector (R, O) characterizing a possible edge at that pixel, where the component $R = \min(R_1, R_2, R_3, R_4)$ is the edge strength and O is the orientation which yields the minimum R_i value. A candidate edge pixel is classified *as* an edge pixel if the magnitude $R \leq T_r$, for a preset threshold $T_r \in (0, 1)$, and if R is the minimum magnitude of all the pixels in a sub-window of $(2D + 1) \times 1$ pixels perpendicular to the orientation O.

Testing of the MSP-RoA edge detector on airborne SAR images [4] has demonstrated it to be an efficient ratio-based edge detector which can produce thin and accurate edge maps in the presence of speckle noise.

In this work, we slightly modified the original MSP-RoA method of [4] by assigning weights to pixels in the averaging process producing P_i and Q_i in each orientation. The pixels nearest the central pixel are assigned more weight than those farther from the central pixel, in order not to degrade edge strength for very fine edges when a large window size is used.

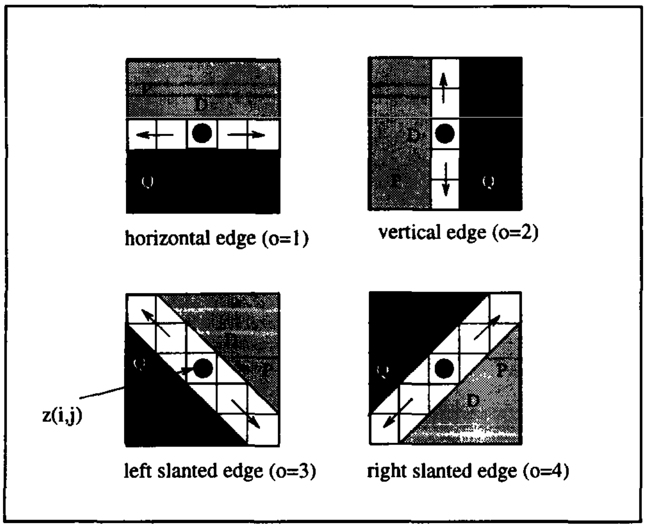

Figure 1: MSP-RoA scheme

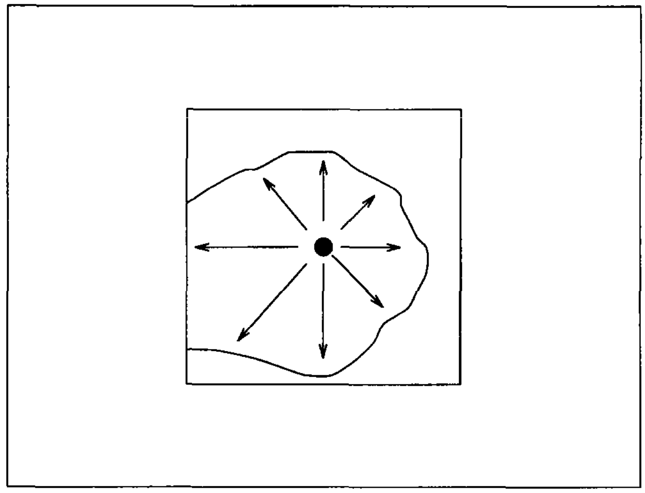

Figure 2: Using edge information to define the *valid* region in the filtering window

4. THE MODIFIED LEE FILTER

Although the original Lee multiplicative filter performs very well at noise smoothing in low variance areas, it tends to preserve speckle noise near edges. Since ratio-based edge detectors are able to ignore speckle in detecting edges in SAR images, we have used the edge map produced by the MSP-RoA edge detector to improve the performance of the Lee multiplicative filter.

By using the edge information obtained from the MSP-RoA edge detector, it is possible to refine the definition of the local neighbourhood over which local statistics are calculated, thus improving the homogeneity of the neighbourhood and the quality of the estimates. The improvement in the performance of the Lee multiplicative filter is most notable in high variance areas near edges. Figure 2 shows how knowledge of an edge contour is used in delimiting the neighbourhood for local statistical analysis.

In a filtering window of a given size, all the pixels are classified as belonging to one of two classes, thus allowing the definition of two regions within the window, the *valid* and *non-valid* regions. The *valid* region starts with the central pixel in the filtering window, and is grown uni-dimensionally in eight directions, along the arrows indicated in Figure 2. When the *valid* region reaches an edge point as determined from the MSP-RoA edge map, or when it reaches the window boundary, the region stops growing in that direction. In this way the filtering window is separated into two regions and only the pixels in the *valid* region along the eight directions are included in further statistical calculation.

In our modified Lee multiplicative filter, edge information is thus utilized in defining the filtering window size and shape. Since $\bar{z}$ and $\mathrm{Var}(z)$ are calculated as the mean and variance only of those pixels in the *valid* region they will yield more accurate estimates *near* an edge, so that the modified filter can smooth the speckle in edge areas while preserving the sharpness of edges.

In addition, our edge-enhanced filtering scheme uses an iterative application of the modified Lee mutiplicative filter, with an automatic updating of the filter parameter σ_v at each pass of the filter. In this work, σ_v is estimated from the image data using the method outlined in Section 2.4, and is then used to control the filtering process.

The edge-enhanced filter outlined here can be used with the MSP-RoA edge detector generating a new edge map on each iteration. However, since the MSP-RoA edge detector can produce very good estimations of edge maps for SAR images, even with significant speckle noise, we have chosen to simply apply it once only prior to filtering and to re-use the result on each iteration, thus saving computational time.

5. RESULTS AND DISCUSSION

The iterative application of the edge-enhanced modified Lee filter was tested on synthetic speckled images and the results compared with similar iterations of the original Lee mutiplicative filter. Figure 3(a) shows a clean, original image which is corrupted in Figure 3(b) by a model of four-look amplitude SAR speckle using a method described in [6]. The speckle noise in Figure 3(b) is unity mean but is not white, as it exhibits small spatial correlation in both directions. We use these images to demonstrate the performance of the algorithms, measuring noise smoothing both by the standard measure of speckle suppression as the standard deviation σ_v of the noise remaining after filtering, as well as by the traditional measure of noise smoothing via the Mean Square Error (MSE). Because we are working with synthetic image data, the clean image is known. Hence, the global MSE for the noisy image and filtered images can be calculated when we test the synthetic image. Noise suppression near edges is highlighted by improved MSE values and by inspection of the visual clarity of the filtered images.

Figure 3(c) and 3(d) show the results of smoothing Figure 3(b) by the iterated Lee filters, using a filtering window size of 11 × 11 on each of three iterations. For both filters, the parameter σ_v is automatically estimated and updated. Figure 3(c) shows the result of iterating the Lee multiplicative filter without the addition of edge information, while Figure 3(d) shows the result of the edge-enhanced modified Lee filter. The MSP-RoA parameters used are: window size 11 × 11, threshold $T_r = 0.75$ and correlation parameter $D = 1$. These test results show that the noise is greatly reduced (σ_v in the homogeneous areas is reduced from 0.218 in Figure 3(b) to 0.014 in Figure 3(c) and to 0.013 in Figure 3(d)); yet the edges remain sharp, especially in Figure 3(d). Moreover, the overall mean squared error is reduced from 751 in Figure 3(b) to 230 in Figure 3(c) and to 153 in Figure 3(d). The reduction in the noise in Figure 3(d) is significant, and compares very favourably with other methods of speckle smoothing (e.g. [6, 8]). The quality of the results may be attributed to the ability of the edge-enhanced modified Lee filter to smooth noise especially in the high variance areas on either side of edges including finely defined edges.

Method	Parameters	Fig.	mse	σ_v
Original	–	3(a)	0	0.031
Speckled	–	3(b)	751	0.218
Modified Lee	Mask = 11 × 11, 1 pass		176	0.045
Modified Lee	Mask = 11 × 11, 2 passes		159	0.047
Modified Lee	Mask = 11 × 11, 3 passes	3(d)	153	0.013
Lee mult	Mask = 11 × 11, 1 pass		228	0.030
Lee mult	Mask = 11 × 11, 2 passes		227	0.028
Lee mult	Mask = 11 × 11, 3 passes	3(c)	230	0.014

Table 1: Quantitative comparison of selected noise smoothing results on the image of Figure 3(b).

6. CONCLUSIONS

The edge-enhanced modified Lee filter performs well, especially in high variance regions, because it uses edge information to refine the filter's local statistics estimation. This edge-enhanced filtering process may be used with different edge detectors and filters to improve the performance of other adaptive edge-preserving noise-smoothing filters based on local statistics. The authors are continuing this research by using the edge-enhanced modified Lee filter to pre-process airborne SAR images prior to their segmentation.

7. REFERENCES

[1] J.S. Lee, 'Speckle analysis and smoothing of synthetic aperture radar images', *Computer Graphics and Image Processing*, Vol. 17, pp 24-32, 1981.

[2] J.S. Lee, 'Refined filtering of image noise using local statistics', *Computer Graphics and Image Processing*, Vol. 15, pp 380-389, 1981.

[3] J.S. Lee and I. Jurkevich, 'Segmentation of SAR images', *IEEE Trans. Geoscience and Remote Sensing*, Vol. 27, No 6, pp. 674–680, Nov 1989.

[4] S.S. Ganugapati and C.R. Moloney, 'A ratio based edge detector for speckled images based on maximum strength edge pruning', *Proceedings of ICIP-95*, Vol II, pp. 165–168, Washington, D.C., October 1995.

[5] D.M. Smith, 'Speckle reduction and segmentation of Synthetic Aperture Radar images', *International Journal of Remote Sensing*, Vol. 17, No 11, pp. 2043–2057, 1996.

[6] M.R. Zaman and C.R. Moloney, 'A comparison of adaptive filters for edge-preserving smoothing of speckle noise', *Proceedings of ICASSP-93*, pp. V77-80, Minneapolis, Minnesota, April, 1993.

[7] C. Moloney, 'Smoothing of SAR image speckle noise by multiplicative point estimation filters', *Proceedings of ICIP-96*, Vol III, pp. 907–910, Lausanne, September 1995.

[8] G. Ramponi and C. Moloney, 'Smoothing speckled images using an adaptive rational operator', *Signal Processing Letters*, Vol. 4, No 3, pp. 68-71, March 1997.

[9] C. Ju and C. Moloney, 'An edge-enhanced segmentation method for SAR images', *Proceedings of IEEE Canadian Conf on Elec and Comp Engr (CCECE-97)*, pp. 599–602, St. John's, Canada, May 1997.

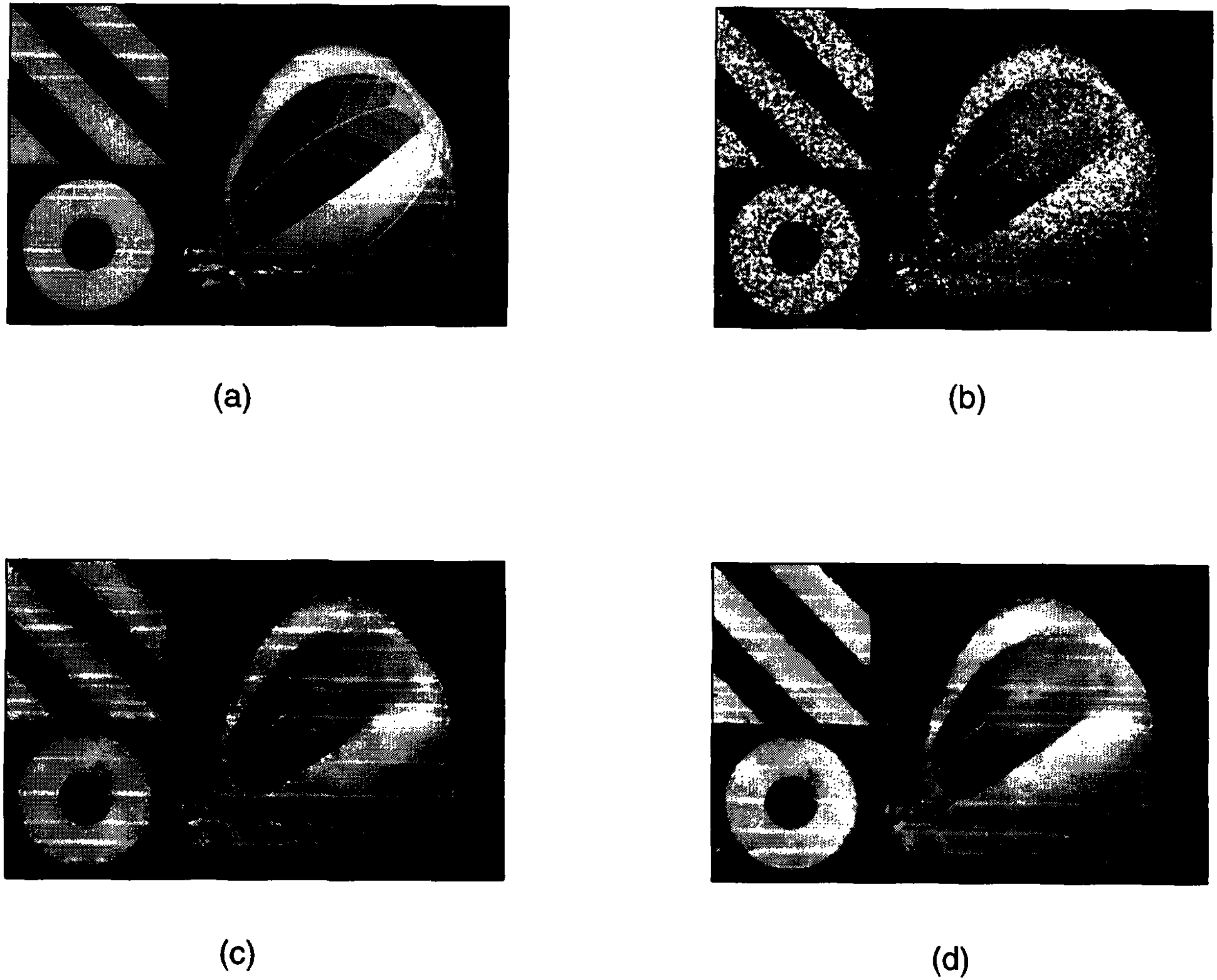

Figure 3: Speckle noise smoothing results: (a) Original image; (b) Corrupted with synthetic four-look SAR speckle noise; (c) Smoothed using an iterative Lee filter; (d) Smoothed using the iterative edge-enhanced modified Lee filter.