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**A COMPARATIVE STUDY OF SPECKLE REDUCTION FILTERS IN SAR IMAGES
AND THEIR APPLICATION FOR CLASSIFICATION PERFORMANCE IMPROVEMENT**

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A COMPARATIVE STUDY OF SPECKLE REDUCTION FILTERS IN
SAR IMAGES AND THEIR APPLICATION FOR CLASSIFICATION
PERFORMANCE IMPROVEMENT *

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ABSTRACT

In this work, an experimental comparative study among several SAR image speckle reduction filters proposed in the literature is made. This comparison is performed in terms of the equivalent number of looks (ENL) of the filtered images obtained from a SAR-580 image over Freiburg, Germany, with one look and linear detection. The compared filters include: box, median, Frost, Lee, Kuan-Nathan, and adaptive windowing versions of the last two filters. The filters by Frost and Kuan-Nathan that were originally proposed for quadratic detection (exponential distribution) were modified to take into account the Rayleigh distribution that characterizes the data, obtained through linear detection. Furthermore, a classification procedure was performed over the same area, showing that a considerable improvement in performance was obtained by reducing the speckle noise prior to the classification.

1.0 INTRODUCTION

It is well known that Synthetic Aperture Radar (SAR) images offer the potential of several advantages over images taken in the visible or infrared regions of the electromagnetic spectrum, like cloud cover penetration, independence of sun illumination, etc. However, SAR images suffer from the presence of a signal-dependent noise called speckle, which is inherent to the coherent nature of the radar imaging process.

Several filters have been proposed for the reduction of the speckle noise. Some of them are heuristic while others are formal procedures that take into account the statistical characteristics of that noise. Among the formal algorithms we may mention the ones proposed by Lee (1981), Frost et al (1981) and independently by Kuan et al (1987) and Nathan and Curlander (1987).

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In this work a comparison of the performance of these filters was made in terms of the equivalent number of looks (ENL) obtained with the use of each filter on a SAR-580 image taken over Freiburg, Germany.

Adaptive versions of Lee's and Kuan-Nathan's filters were also tested, under the adaptation procedure proposed by Li (1988).

The filters by Frost and Kuan-Nathan were originally derived under the assumption of an exponential distribution over homogeneous areas, that assumes a quadratic detection (and one look) on the SAR processor. We modified these filters to take into account the fact that the image under test was obtained with linear detection (and one look), which implies a Rayleigh distribution over those areas.

An evaluation of the classification performance before and after filtering was performed, pointing to the necessity of reducing the speckle of these one-look images prior to the classification, in order to obtain a reasonable probability of error.

2.0 BRIEF REVIEW OF THE COMPARED FILTERS

2.1 BOX FILTER

It is the simplest possible filter for smoothing noise. It consists of a moving average on a square window over the image. It tends to decrease the noise at the price of a considerable decrease in detail.

2.2 MEDIAN FILTER

In its 2-D version, this technique substitutes the center pixel on a window with an odd number of pixels by the intermediate value in this window. This nonlinear filter has been used for decreasing the speckle noise, specially in geologic scenes (Sadjadi, 1990).

2.3 LEE'S FILTER

A multiplicative model is adopted for the noise. A linearization by Taylor expansion around the mean values is made and only the linear terms are retained.

The resulting linear model transforms the multiplicative noise into an additive noise that is uncorrelated with the signal and, therefore, a standard linear mean square error pointwise filter (Wiener filter) is obtained. The a priori statistics are obtained by local measurements of the noisy signal by using the multiplicative model.

2.4 KUAN'S ET AL AND NATHAN-CURLANDER'S FILTERS

A multiplicative model is also used but it is transformed into an additive noise, that is uncorrelated with the signal, with no approximations involved. The pointwise estimation is also performed by the Wiener filter with a priori statistics estimated from the noisy signal.

2.5 FROST'S FILTER

This is a linear convolutional filter, derived from the minimization of the mean square error under the multiplicative noise model. It incorporates the statistical dependence of the original signal through the assumed exponential spatial correlation function.

2.6 LI'S ADAPTATION PROCEDURE

The ratio between the local variance of the original signal (calculated from the statistics of the noisy signal under the multiplicative model) and the variance of the noisy signal is computed. This ratio varies between 0 and 1. High values indicate fine detail, and possibly, the presence of an edge. Low values indicate smooth, homogeneous regions. The computed ratio controls the size of the window used for the derivation of the local statistics that is necessary for Lee's, Kuan-Nathan's and Frost's filters. High (low) values indicate the use of small (large) windows.

2.7 EDGE DETECTION FOR THE COMPUTATION OF LOCAL STATISTICS

In this paper an attempt was made to detect local edges and compute the local statistics only on the side of the edge that is statistically closest to the central area of the edge. We used the procedure proposed by Rabbani (1988) for Poisson noise degraded images.

3.0 IMPLEMENTATION OF THE FILTERS

The box and median filters were implemented on a 5 x 5 window. Lee's and Kuan-Nathan's filters were either implemented on a pixel 5 x 5 window for the computation of the local statistics, or through the adaptation proposed by Li, where the correspondence of the ratio (R) mentioned in section 2.6 and the size of the window is selected through Table 1.

Table 1. R x Window Size

R	Window size
$0 \leq R < 0.2$	9 X 9
$0.2 \leq R < 0.4$	7 X 7
$0.4 \leq R < 0.6$	5 X 5
$0.6 \leq R < 0.8$	3 X 3
$0.8 \leq R < 1.0$	Central pixel

The determination of the spatial correlation coefficient of the original signal in Frost's filter from the noisy signal was not attempted. Instead, several values were used and the corresponding experimental results were evaluated.

The filters by Frost and Kuan-Nathan were modified for the linear detection, one-look image under test, by selecting accordingly the appropriate value of the standard deviation σ_n of the multiplicative noise

($\sigma_n = 1$ for quadratic detection, one look and $\sigma_n = 0.5227$ for linear detection, one look)

4.0 FILTERING RESULTS

The previously described filters were applied to a SAR-580 image taken over an area near Freiburg, Germany. The 512 x 512 images were obtained on the L and X bands, with linear detection and one look. Figure 1 displays the location of the area.

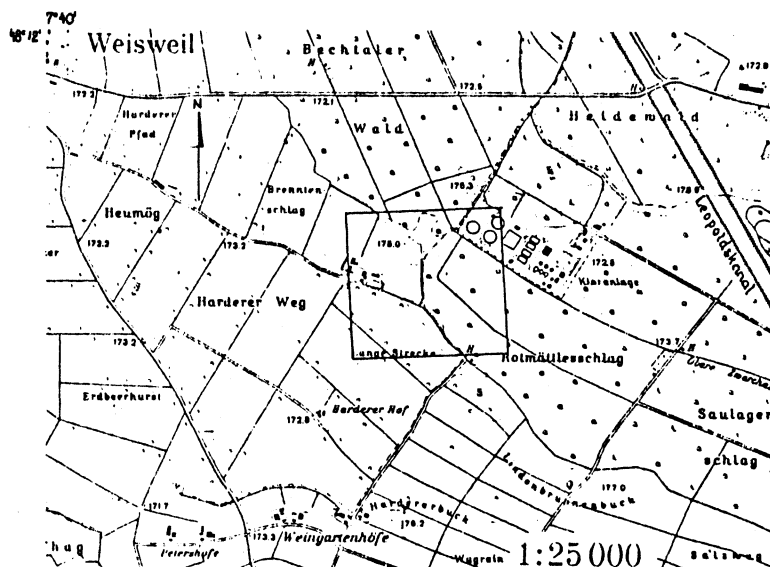


Figure 1 - Location of the area under study.

Figures 2 and 3 show the original L and X bands, respectively, of the same area.

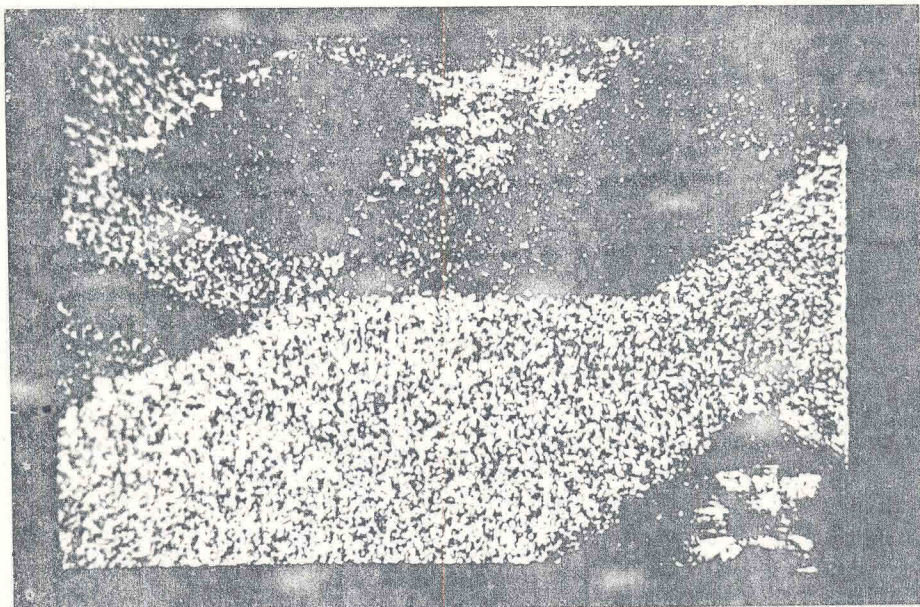


Figure 2 - L band original image.

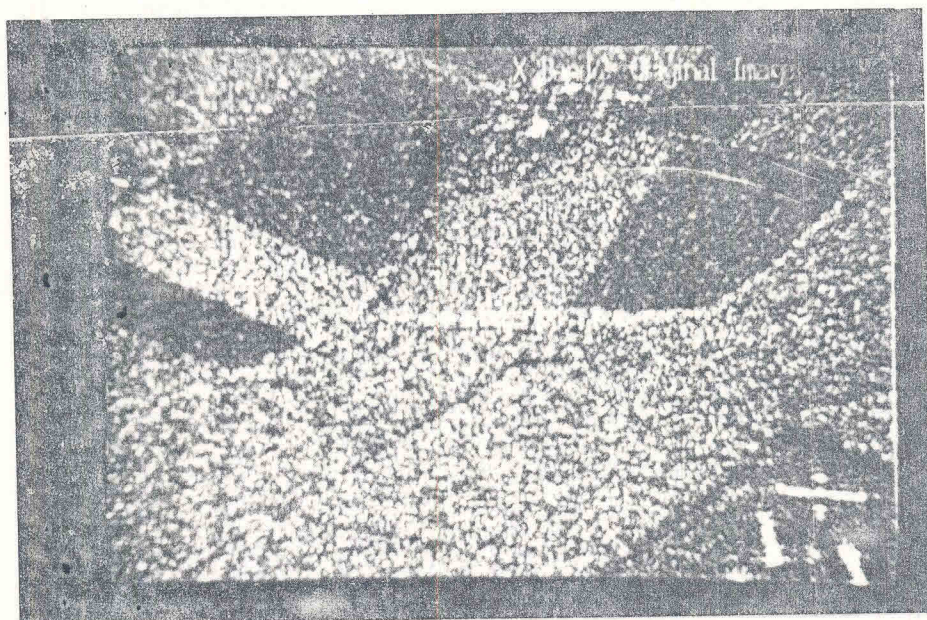


Figure 3 - X band original image.

The visual results of applying the adaptive versions of Lee's and Kuan-Nathan's filters to the right side of the L band image are presented on Figures 4 and 5, respectively.

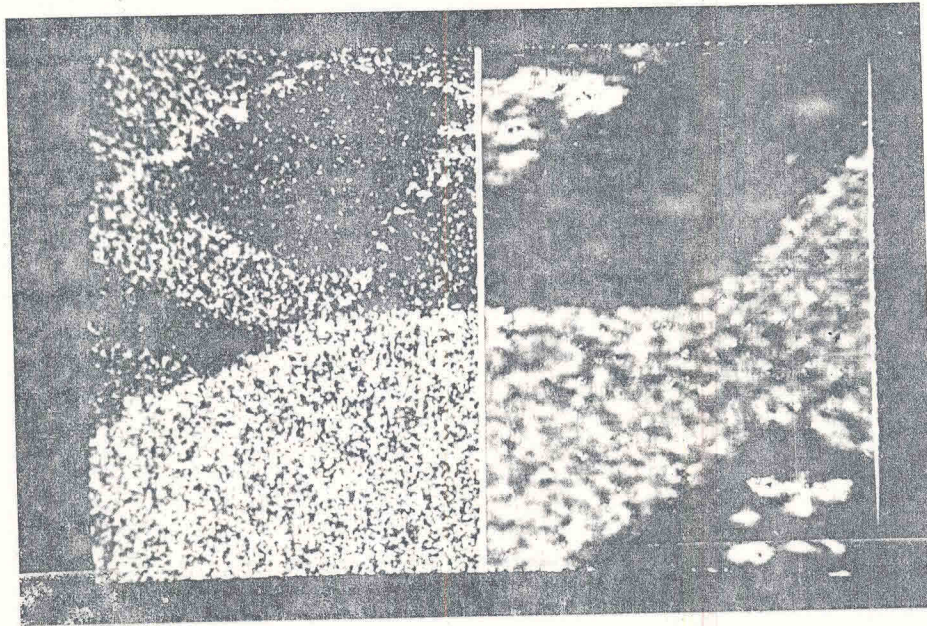


Figure 4 - L band - Adaptive Lee's Filter.

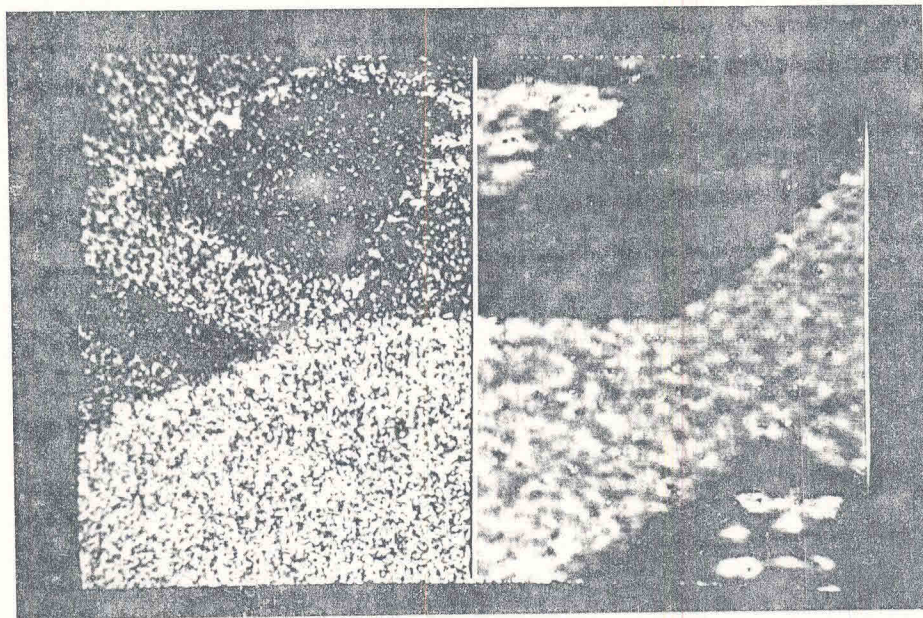


Figure 5 - L band - Adaptive Kuan-Nathan's Filter.

The application of Frost's et al filter on the L band, with an assumed correlation coefficient (ρ) between pixels separated by 1 unit equal to .8 results on Figure 6.

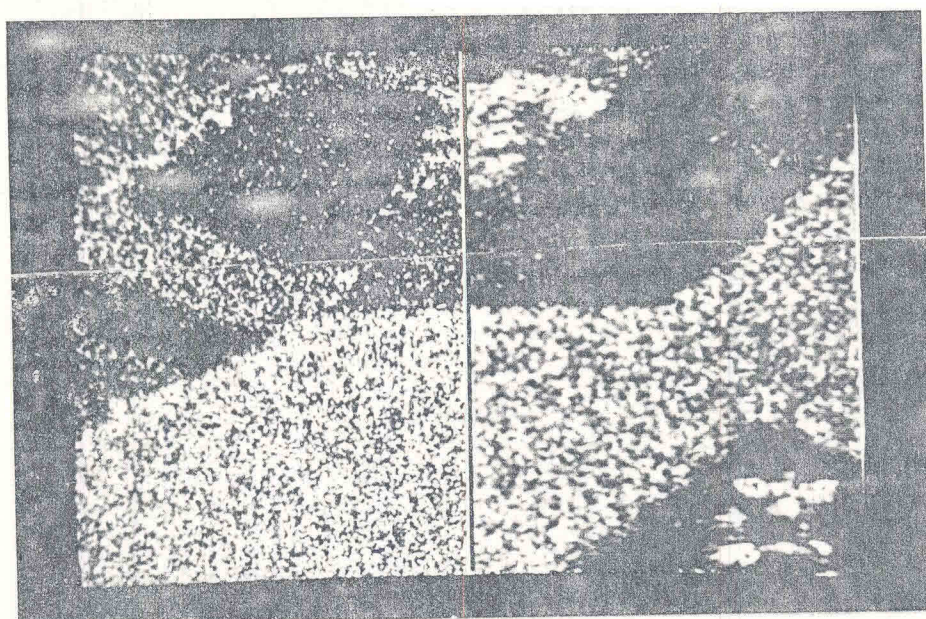


Figure 6 - L band - Frost's et al Filter $\rho = .8$

Figure 7 displays the filtered X band image by the adaptive version of Kuan-Nathan's filter.

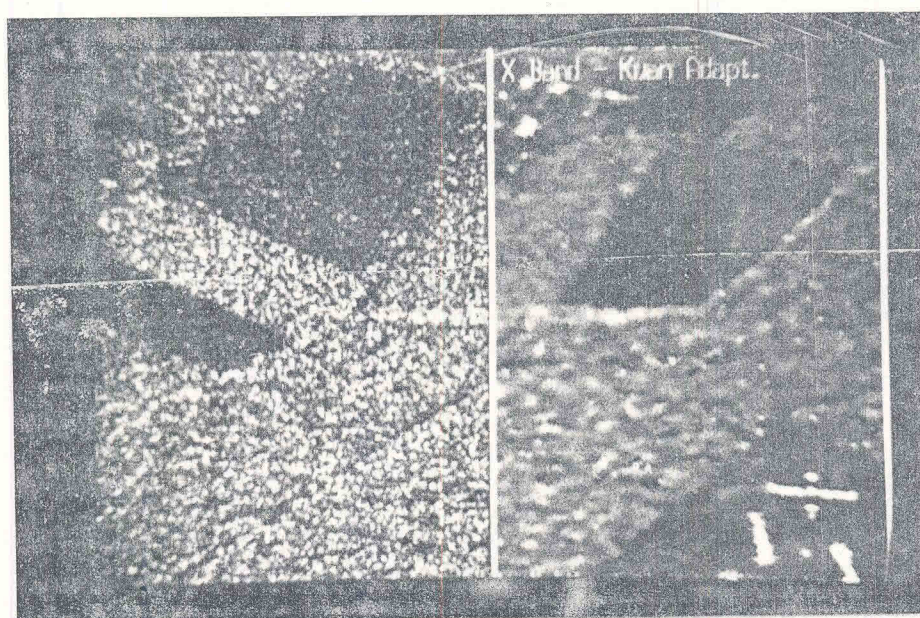


Figure 7 - X band - Adaptive Kuan-Nathan's Filter.

The multiplicative model implies a proportionality between the standard deviation (denoted by d.p.) and the mean (denoted by m) over homogeneous areas. Although there are not strictly homogeneous areas in the available image, the plot of the estimated d.p. versus m, using a set of small windows over the most homogeneous area available in the original image shows that the multiplicative model seems to fit reasonably well the speckle noise in the image. Under the linear detection, one look conditions (Rayleigh distribution), the tangent should theoretically be equal to .5227 and the line should pass through the origin. We obtained (Figure 8) through the least-squares fit a tangent equal to .5278 and an offset of -.3. This offset is probably due to noise present in the acquisition of the image (Durand et al, 1987).

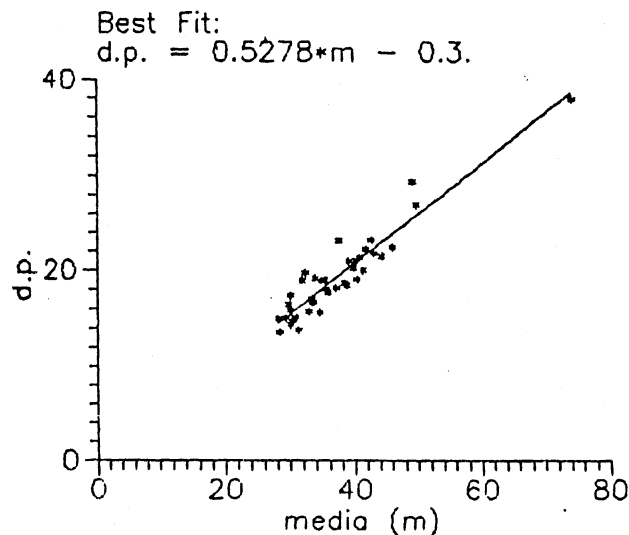


Figure 8 - Plot of the standard deviation (d.p.) versus mean (m) over small windows on a homogeneous area on the original image.

The histograms of the right half side of the L and X bands images are displayed on Figures 9 and 10, respectively. This area contains two distinct regions: one lighter (mostly forest) and one darker (mostly bare fields). Without the presence of the speckle noise one would theoretically expect two narrow peaks in the histogram. However, the speckle noise masks this bimodal distribution, although a slight peak on the histogram of the L band around the gray level equal to 90 indicates the presence of a mixture of Rayleigh distributions.

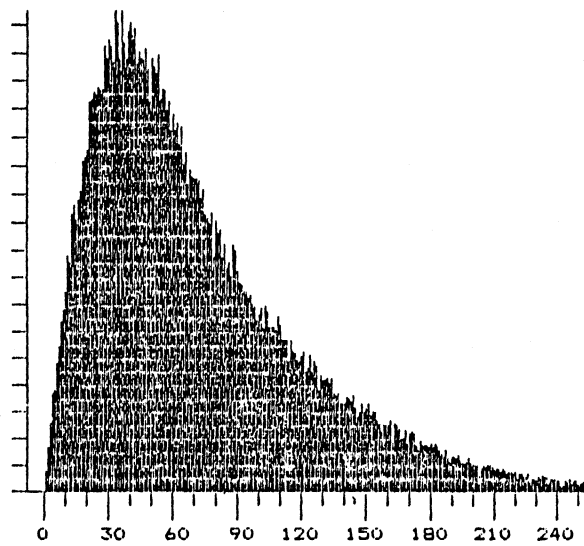


Figure 9 - Histogram of L band.

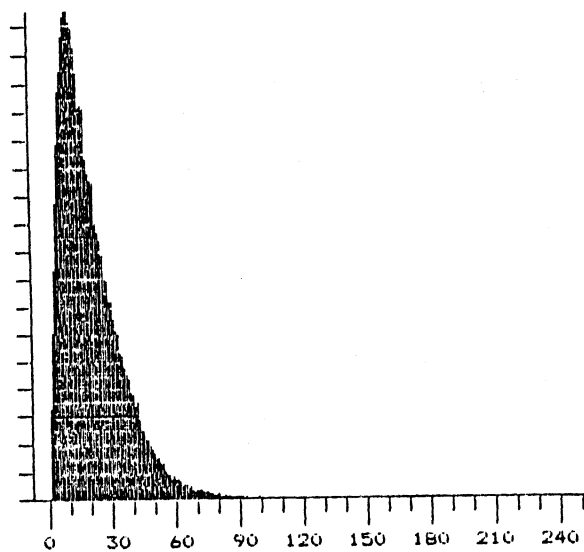


Figure 10 - Histogram of X band.

After the speckle noise reduction by applying the adaptive version of Kuan-Nathan's filter, the bimodal nature of the histogram of the filtered band image is clearly depicted on Figure 11. Observe that the histogram consists of two reasonably symmetric parts and that the mode which is approximately equal to the mean value of the lighter distribution is around 100. This fact should be compared to the slight peak around 90 of Figure 9 and take into consideration that the average value of the Rayleigh distribution, which is to be estimated, (a) is related to the mode (m) by $a = \sqrt{\pi/2} m \approx 1.25 m$.

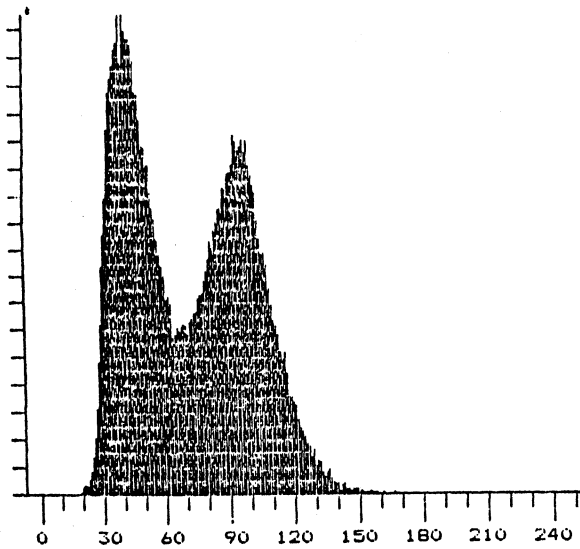


Figure 11 - Histogram of filtered image - Adaptive version of Kuan-Nathan's filter.

The comparison of the different filters in terms of the reduction of speckle noise was performed by estimating the mean value ($\bar{V}_e$) and the standard deviation (σ_{V_e}) over a number of small windows on a homogeneous area of the image deriving through least squares best fit the ratio $\frac{\bar{V}_e}{\sigma_{V_e}}$ (as in Figure 8) and calculating the equivalent number of looks (ENL) for linear detection as:

$$ENL = 0.2732 \left(\frac{\bar{V}_e}{\sigma_{V_e}} \right)^2 \quad (1)$$

Table 2 presents the ENL's for the various filters. It should be remarked that these results are approximated due to the lack of truly homogeneous areas in the available image.

Table 2. Comparison the ENL for Different Filters

IMAGE/FILTER	ENL
Original	1.0
Box 5x5	5.5
Median 5x5	4.3
Lee 5x5	5.1
Adapt. Lee	8.2
Kuan-Nathan 5x5	5.1
Adapt. Kuan-Nathan	8.6
Frost $\rho=0.6$	3.8
Frost $\rho=0.8$	4.4

It can be observed that the adaptive versions of Lee's and Kuan-Nathan's filters perform best in terms of ENL.

The application of the edge detection technique originally proposed by Rabbani for Poisson noise for estimating local statistics was also attempted but it gave no substantial improvements in filtering performance. This is probably due to the fact that the area that was filtered exhibits a small percentage of edge pixels. More conclusive tests should be performed in the future, involving images with a greater percentage of edge pixels.

5.0 CLASSIFICATION RESULTS

Figure 11 clearly confirms the benefit of filtering the speckle noise on one look SAR images, prior to any classification procedure (Benelli et al, 1986; Durand et al, 1987), in order to obtain a better separation of class distributions.

A supervised classification was performed under the maximum likelihood criterion and gaussian assumption, using the L and X bands, both before and after filtering by the adaptive version of Kuan-Nathan's filter. Although the gaussian assumption is questionable for describing class distributions on the original image, Figure 11 suggests that it seems reasonable for a pointwise filtering procedure like the adaptive Kuan-Nathan's filter. Furthermore, it should be even more adequate for convolutional linear filtering procedures like Frost's filter, by invoking the central limit theorem, although this was not yet checked experimentally.

Table 3 and 4 presents the classification results before and after filtering, respectively.

Table 3. Classification Matrix-Original Image

CLASSES	REJECTED (%)	CLASS 1 (%)	CLASS 2 (%)	CLASS 3 (%)
1-Bare Field	2.1	69.9	7.2	20.8
2-Forest	5.5	12.9	47.9	33.6
3-Culture	1.6	23.7	14.6	60.1

Average performance: 56.52%
Average rejection: 3.75%
Average confusion: 39.73%

Table 4. Classification Matrix-Filtered Image

CLASSES	REJECTED (%)	CLASS 1 (%)	CLASS 2 (%)	CLASS 3 (%)
1-Bare Field	3.9	87.2	3.8	5.1
2-Forest	3.2	1.6	89.6	5.6
3-Culture	0.6	4.6	4.9	90.0

Average performance: 88.89%
Average rejection: 2.93%
Average confusion: 8.18%

The comparison of Tables 3 and 4 demonstrates a substantial improvement in classification performance by prior filtering the speckle noise. It should be pointed out that both classification matrices represent somewhat optimistic results, since both training and test areas were the same.

6.0 CONCLUDING REMARKS

A comparison of the equivalent number of looks (ENL) obtained through several speckle reduction filters was made. This comparison demonstrates that the adaptive versions of Lee's and Kuan-Nathan's filters perform best. In order to be complete, this comparison should also evaluate the resolution loss of each of the filters. This work is being planned in the near future by testing the filters on simulated speckle images with ideal edges.

The application of a speckle reduction filter before the thematic classification considerably improved the classification performance of a maximum likelihood classifier under the gaussian assumption.

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