Assessment of Filters to Reduce Speckle
Prior to the Automatic Extraction of Very Thin Slightly Bright Features

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Abstract: There are many fields of application for SAR imagery that requires the detection of very thin features. These features often comprise many very small point-like and line-like features. To detect small features from noisy SAR imagery, speckle noise should be reduced prior to high level feature extraction, but features should not be wiped out in the process. To select the most appropriate filter for automated detection of very thin features slightly brighter than the background, the Lee filter, the enhanced Lee filter, the Frost filter, and the small-feature preserving despeckling filter (SFP) developed by one of the authors have been quantitatively evaluated using a ship wake feature in a 6 look ERS-1 image. The ability to reduce speckle and the ability to preserve the contrast of small features were evaluated. To measure the contrast of real images, we developed a new method, in which feature masks and the surrounding background masks are created at multiple threshold levels and the ratios and the differences are calculated from the average pixel values of the feature and the surrounding areas. Among the filters examined, the SFP filter was the most suitable for subsequent automated extraction of very thin slightly bright features.

1. Introduction

SAR data is becoming increasingly popular with ERS-1, JERS-1, ERS-2 and RADARSAT in service. As is well known, however, one of the primary drawbacks in feature extraction and detection from SAR imagery is that SAR images suffer from speckle noise, a phenomenon inherent in coherent imaging[1]. This speckle noise, which is multiplicative and proportional to pixel intensity in theory, has a significant effect on many kinds of image analysis and interpretation, and so should be removed as much as possible prior to feature extraction. Much work has been done on the development of despeckling filters[2–25], but the performance of...
these filters is not always satisfactory for the intended uses of the images.

Just as there has been considerable work on the development of despeckling filters, there has also been work done on their evaluation\(^{26-28}\). Recently Lee et al\(^{29}\) made an extensive review of despeckling filters and evaluated them with respect to the retention of mean values in homogeneous regions, speckle reduction, preservation of edges, lines and point targets, and retention of texture information using simulated SAR images. For real images, however, there has been only qualitative visual evaluation. Since the features in real SAR imagery, especially very small or thin features, are quite different from simple simulated features, there is an urgent need to study real features themselves.

The degree to which speckle must be reduced often depends on what an image is to be used for and what features are to be examined. Despeckling filters also bring with them problems in that they do not just remove speckle noise but have an impact on legitimate image information as well. The user generally wants to minimize this effect. However, the type and degree of image degradation that can be tolerated is also largely dependent on the nature of the features of interest as well as on the methods of feature extraction to be used subsequent to despeckling.

We have been interested in very thin terrain features (whose widths are often smaller than or comparable to the resolution size). Of particular interest in this study are features slightly brighter than the background. Such features are often found extensively on water surfaces. Various examples of oceanic features, such as oceanic rings, eddies, currents, bathymetric features, internal waves, and ocean fronts, are seen in SEASAT images\(^{30}\). They are relatively easily detected visually and are often keys to visual interpretation. They are, however, very difficult to detect automatically. We have developed a method to detect various features by integrating not only spatial and geometrical information but also non-image information to intensity information\(^{31-34}\) and have successfully detected very thin features\(^{35-38}\). However, although powerful, this method still needs some degree of speckle reduction prior to image analyses even in an analysis of multi-look images.

The objective of this study is to select the most suitable filter with which to reduce speckle prior to the automatic extraction of very thin features, specifically slightly bright features. The filters need to be evaluated with respect to their ability to reduce speckle noise in the background and their ability to preserve small or thin features under the same condition (filter parameters should not be changed during the evaluation). They also need to be evaluated using real images because these features are far more complex than those a simple multiplicative speckle model can simulate.

This paper begins by examining the characteristics of the so called "lines" in real SAR images using a ship wake as an example, and briefly describes the subsequent automatic extraction method of these features. The whole approach to the quantitative real image evaluation and the approach to the development of a new method for measuring the contrast of real image features are then described. Finally, experimental results are described and discussed. The most suitable filter for the purpose is selected in the conclusion.

2. Data Set and Image Characteristics

Figure 1 shows a 1,000 × 1,000 ERS-1 SGF (SAR Georeferenced Fine-Resolution) product image of Lake St. Clair (on the border of Michigan, USA and Ontario, Canada) used in this study. The data was acquired on June 18, 1992, at 4:16 in the afternoon. The number of processed looks is 6. The image is a 16 bit so-called “amplitude” image obtained from the square root of the average of 6 independent -look “intensity” images. The spatial resolution is nominal 30m azimuth by 35m ground range and the pixel spacing is 12.5m by 12.5m. The land portion on the left is the city of Detroit, Michigan, USA. Two
Figure 1. The original ERS-1 image of the lake St. Clair area.

large ships are moving towards the upper right corner. Along the shore of Detroit, a few small ships, probably motor boats, are moving parallel to the shore. Weather data reveals that this is a relatively windy and rainy day after heavy rain fall (34.4mm) on the day before. Therefore, the ground is very wet and appears very dark except for the bright returns from the buildings. The average windspeed of the hour the image data was acquired was 35 km/h, and there was 6.4 mm of rain that day. This made the entire water surface quite rough.

Original features and the filtering effect on them are examined in detail using a small 100 by 200 area shown in Figure 8a. The area was selected because it has a very clear ship wake, thus making it relatively easy to examine the effects of filtering. Both arms of the wake are clearly visible, forming a near-perfect “V” about 200 pixels in length and forming an angle of about 15 degrees.

One important aspect of the data set in question here, and specifically of ship wake features, is that while the eye perceives them as straight lines, they are actually a series of points or “blobs.” Figure 2 shows 3D plots of the 100 x 200 pixel ship wake area above a sequence of three thresholds for purposes of clarity. Figure 2a is cut at a pixel value of 800, 2b at 900, and 2c at 1,000. Another way to demonstrate the nature of the ship wake structure is with its contour map (See figure 3). This contour map actually only contains one level, at the mid-range of the data, but
provides quite a good qualitative illustration of the nature of the image. These figures clearly demonstrate that the small features associated with the ship wake are much more complex than those a simple multiplicative noise model can simulate. While the human eye can smooth random and homogeneous noise naturally, automatic detection needs to smooth the noise using a speckle reduction filter. Here lies a potential for a problem.

Successful automatic detection of V-shape ship wakes after speckle reduction does not directly search for V-shapes but is carried out roughly as follows: A filtered image is binarized at many threshold levels to extract bright image objects. Starting from the brightest image objects (because they draw the initial human attention in a visual search), the local line-likeness of each pixel belonging to each image object is evaluated at each brightness level. Those line-like pixels are then summed over all brightness levels so that highly line-like pixels show high values. A mid-scale line-like object may be formed from a group of continuous highly line-like pixels and then a global-scale candidate line feature that might extend roughly to a ship wake length may be formed from several groups of mid-scale line-like objects. Finally a candidate line feature may intersect with other candidate line feature to form a V-shape.

Thus we can see easily that the contrast of feature plays a very important role in an initial stage of successful V-shape ship-wake detection. Therefore, the evaluation of de-speckling filters should include the preservation of contrast between features and their immediate backgrounds as well as the reduction of the background speckle when they are
evaluated as a preprocessing tool of such a feature extraction.

3. Approach

Since very thin features cannot be described in a simple model as demonstrated in the previous section, it is desirable and necessary to use a real image instead of a simulated image for the quantitative evaluation of filters. Only speckle reduction measures, however, are applicable to real images. As no measures were available for contrast preservation, we developed a new method. We evaluated the ability for speckle reduction using the existing measure and evaluated the ability for contrast preservation using our new method. We then integrated the results later.

We employed the following speckle index \( \beta \) defined by Lee et al\(^{29} \) to evaluate speckle reduction capability.

\[
\beta = \frac{\sqrt{\text{var}(\bar{x})}}{E[\bar{x}]}
\]

where \( \bar{x} \), \( E[\bar{x}] \) and \( \text{var}[\bar{x}] \) are the pixel value, the mean and the variance of the filtered SAR image, respectively.

We developed a new contrast measuring method for real images as follows:

Our approach starts by first extracting features and their immediate backgrounds from the original image. Since pixels belonging to ship wakes are not precisely defined, extracting only the features and generating precise feature masks is not a trivial task. We use multiple masks, each at different thresholds, rather than just one. All masks are generated mathematically (rather than by hand) since it is critical on features this small to include just appropriate pixels. The corresponding background masks are then created by dilating the target masks and eliminating the target portions. The width of a background mask should be narrower than the resolution.

Second, the de-speckling filters are applied to the original image. Each filtered image is then multiplied by each of these masks (target and background at each threshold). Each of these images is then read by a simple program that goes through and finds all the distinct blob-like features and then computes the mean and standard deviation of the set of pixel values in each. The means for target features and their immediate background are then compared in terms of both their ratios and their absolute differences.

4. Experiment

The original image was filtered using the Lee filter\(^{4,9} \), the Enhanced Lee filter\(^{20} \), and the Frost filter\(^{7} \). The same image was also filtered with the small feature preserving (SFP) filter (see Appendix). The parameters of the Lee filter was calculated from the image statistics. The Frost filter was used with the damping set to 1 to preserve sharp edges better and to reduce the smoothing effect. The SFP filter and the Enhanced Lee filter were used with the number of looks set to 5 because the effective looks

![Figure 4. Target and background masks at three thresholds (pixel values of 1,300, 1,000 and 950)](image-url)
of the ERS-1 SGF products were reported to be 4.9\(^{39}\). A window size of 7 by 7 was selected for all filters to reduce speckle in featureless areas as much as possible without sacrificing computational time.

To create feature masks, the original image was thresholded and binarized at three different, representative levels: pixel values of 1,300, 1,100, and 950. The highest level was selected such that only a few of the very brightest points on the ship wake were retained. The lowest level was selected such that as many points on the ship wake were included as possible without these blob-like features merging with the surrounding area. If blob-like features merged with the surroundings (background), it would be impossible to justify exactly where we split them. The one pixel width of the background masks was employed in the analysis with a desire to be consistent with previous work by Lee et al\(^{29}\).

Figure 4 shows the target and background masks generated at three thresholds: at pixel values of 1,300, 1,100, and 950. In the low threshold masked images, some background features have several corresponding target features.

5. Results and Discussion

Degree of speckle reduction was measured using the speckle index \(\beta\) defined in Eq.(1). Figure 5 shows a plot of \(\beta\) for the entire water surface, the water surrounding the ship wake, and a relatively featureless area of the water surface. The mean filter performance is included for reference. A smaller value means a better speckle reduction capability. All \(\beta\) values of the relatively featureless area were smaller than those in other areas, as expected.

Although all the filters reduce speckle, the Enhanced Lee filter and the Frost filter reduced speckle better than other two filters. The \(\beta\) values of the Enhanced Lee filter and the Frost filter were almost the same as those of the mean filter.

Using the method described in the previous sections, an ability to preserve the contrast of small features was measured for four despeckling filters. The results were surprisingly consistent, although we selected threshold levels rather arbitrarily. The ability decreased in the following order: the SFP filter, the Lee filter, the Enhanced Lee filter, and the Frost filter. This ordering held true for all three threshold levels.

To summarize and demonstrate these general tendency of the contrast preservation, we selected eight blob-like target features at random from each threshold level data and calculated the averages of both contrast measures. Figure 6 and Figure 7 show plots of the average ratios and the average differences of 8 data sets for all filters, respectively.

The SFP filter showed the highest ratios close to the original ratios in all threshold levels with some degradation in darker targets. Although the Lee filter and the Enhanced Lee filter were almost the same in preserving the bright targets next to the SFP filter, the Lee filter was better than the Enhanced Lee filter in preserving the less bright targets. The Enhanced Lee filter blurred darker targets. The Frost filter showed the lowest ratios in all threshold levels and blurred everything. The average difference as another measure of the contrast preservation revealed a similar pattern, as shown in Figure 7.

Because experimental results show that the SFP filter is excellent in preserving contrast and reasonably good in removing speckle, SFP filter seems to be very good in differentiating objects from back-
Therefore we can conclude that the SFP filter is the most suitable filter to preprocess the original image prior to the detection of small or thin line features from a slightly darker background. The Lee filter comes next.

These quantitative results may be seen in real images combining Figure 8 and Figure 9. Figure 8 shows the original and filtered images of the ship wake area. It should be noted that these images are individually stretched to show the ship wakes at a similar brightness. Figure 9 shows the contour maps of each of the images. Again, the contour maps are actually just one contour at the mid-range gray-level of the image. We can see that the Enhanced Lee filter and the Frost filter reduce speckle noise very well. However, the Frost filter over-smoothes everything, both noise and features, including bright point features. The Enhanced Lee filter reduces too many of the intermediate level features, although it leaves bright point targets pretty much alone. On the other hand, the Lee filter and the SFP filter seem to preserve the features well. However, we can see easily that the Lee filter loses the original contrasts very much compared with the SFP filter, and as a result, it has more noise features than the SFP filter.

The performance of the MAP filter with gamma distribution was also investigated, but it was discovered that it creates artifacts surrounding distinct features in the image, which are especially problematic for small medium gray level features such as those in this study. Those artifacts might not be a problem for investigators concerned with large area-like features or isolated distinct features. The Enhanced Lee filter also has a potential of creating artifacts surrounding distinct features but less frequently. In our experiment, the artifacts were not apparent.

6. Conclusion

To facilitate the subsequent automatic extraction of very thin slightly bright features, the Lee, the Enhanced Lee, the Frost, and the SFP (Small Feature Preserving) filters have been quantitatively evaluated in terms of their ability to preserve small features yet to reduce the background speckle noise using a real image. A method was developed to measure the contrast of features in real images by applying multi-level feature masks and surrounding background masks. Considering both the contrast of the feature of interest and the speckle index of the background, it was found that the SFP filter was the most suitable filter to reduce speckle prior to the automated extraction of very thin slightly bright features with the Lee filter coming next. This new work will be critical for helping the selection of a despeckling filter for image processing applications where small feature preservation is a priority.
Figure 8. The original and the filtered images (Note that images are individually stretched)

Figure 9. Contour maps of the original and filtered images
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Appendix

A brief description of the SFP filter should be given here, since it is not widely known. The SFP Filter is a spatially non-linear filter described by an expression similar to the Sigma filter and a filter developed by Ali and Burgel. The estimate of the center pixel value of a moving window is given by

\[ \bar{x}_c = \frac{\sum_{k=-m}^{m} \sum_{l=-n}^{n} w_{kl} z_{kl}}{\sum_{k=-m}^{m} \sum_{l=-n}^{n} w_{kl}} \]  

(2)

where

\[ w_{kl} = \begin{cases} 1 & \text{if } |z_c - z_{kl}| < 2\sigma_c \bar{z}_c \\ 0 & \text{otherwise} \end{cases} \]

Here \( z_c, z_k \), and \( z_l \) are the value of the center pixel, the value of the window pixel at \( k, l \), and the average pixel value of the window pixels, respectively. \( \sigma_c \) is the standard deviation of the multiplicative speckle noise. It can be estimated theoretically or measured from the image. \( 2m+1 \) and \( 2n+1 \) correspond to the window size. Various small or thin features have been successfully detected from several spaceborne SAR images using this filter.

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References

13) Kuan, D.T., Sawchuk, A.A., Strand, T.C. and
34) Iisaka, J. and Sakurai-Amano, T.: PC network of image computing for remote sensing, Proceed-


