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SAR Image Enhancement:
Combining Image Filtering and Segmentation

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Abstract – SAR images are generally affected by speckle noise due to the interference of reflected waves from many elementary scatterers. The speckle complicates image interpretation and reduces the effectiveness of automatic image analysis techniques. A good filter should maintain the signal mean value and reduce the speckle while preserving the edges. Adaptive filters use an estimation of the variation coefficient. The utilization of fixed size windows produces poor estimates. We examine new ways to use image segmentation techniques to improve image filtering processes. In a complex task, the objectives of the first step should be limited in order to obtain reliable results that will be the base of next steps. We use a region growing process to reduce extremum values as a pre-processing step to SAR image filtering.

Keywords: SAR image, filtering, segmentation, region growing, remote sensing.

1- Introduction

Synthetic aperture radar (SAR) systems provide high-resolution images for remote sensing application. The utilization of the microwave band makes the image acquisition mostly independent of weather condition. SAR images are generally affected by speckle noise due to the interference of reflected waves from many elementary scatterers. The speckle complicates image interpretation and reduces the effectiveness of automatic image analysis techniques. The speckle is generally modeled as a multiplicative noise.

A good filter should maintain the signal mean value and reduce the speckle while preserving the edges. Several filtering methods have been proposed such as the Lee filter, the Kuan filter and the Gamma filter [1] [2] [3]. These filters are adaptive and use local statistics on a fixed size window to determine the weighting factor. These filters are better than the Box filter or the median filter because they consider the multiplicative nature of the speckle noise. However, they use an estimation of the coefficient of variation of the signal intensity to make a decision about the homogeneity of an area. In some cases, this estimation may not be reliable which produces poor results.

In remote sensing, a segmentation process could be used to detect land fields and to improve pixel classification. The segmentation of SAR images is greatly complicated by the presence of coherent speckle. The complex structure of the SAR images requires the utilization of a composite criterion for the segmentation. SAR image filtering is often used as a pre-processing step.

We examine new ways to use image segmentation techniques to improve image filtering processes. In a complex task, the objectives of the first step should be limited in order to obtain reliable results that will be the base of next steps. We use a region growing process to reduce extremum values as a pre-processing step to SAR image filtering.

2- Utilization of spatial information

2.1- SAR image model

Radar images are mainly characterized by the presence of speckle [2]. The radar signal can be modeled as a random process. The variance of the signal can be reduced by performing multi-look processing, i.e., by averaging L independent views of the data. The probability density

function of L-look signal follows a Gamma distribution:

$$p(I) = \frac{1}{\Gamma(L)} \left(\frac{L}{R} \right)^L I^{L-1} \exp\left(-L \, I \middle/ R \right)$$

where I is the signal intensity and R is the ground reflectivity of a homogenous area. In this case, the mean value and the standard deviation of the signal intensity are: $\mu_I = R$, $\sigma_I = R / \sqrt{L}$. As the standard deviation varies with the mean value, we generally use the variation coefficient to express the signal variation: $C_I = \sigma_I / \mu_I = 1 / \sqrt{L}$. Figure 1 illustrates de multiplicative nature of the radar signal. The variance increases with the mean value. The figure shows clearly the large variance of the radar signal.
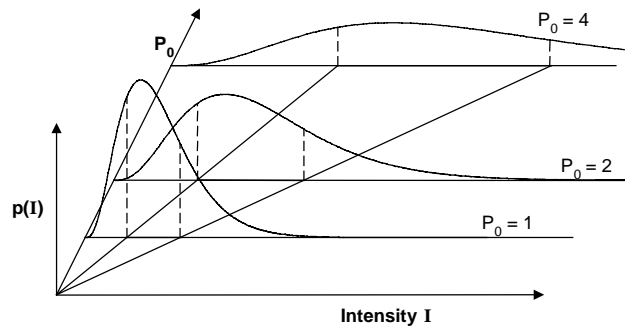

Figure 1: The probability density function of the radar signal.

2.2- Filtering and segmentation

The spatial information is important in filtering and segmentation techniques. Classical linear filtering techniques perform convolution operations using fixed window sizes. The window is centered on the output pixel and different weight values are assigned to each window cell. Different filters result from the utilization of different weighting functions. This is a linear transformation with no decision involved. High frequency attenuation filters are used to reduce the noise by smoothing the image. Gradient or pass-band filters are used into edge detection processes. Adaptive image filtering techniques want to smooth the image inside homogeneous areas (regions) while preserving lines and region contrasts (edges). A decision process is used to detect edges and avoid edge blurring.

In SAR image filtering, the image is viewed as a stochastic process. Pixel density probabilities are calculated. The image filtering is considered as an estimation problem: estimate the truth pixel values from the observed values. Generally, the best estimate corresponds to the mean value over a set of homogenous pixels (from a same population). This results in calculating the mean value over a window. Correct values are obtained if the window cover homogenous areas. Adaptive techniques try to detect if the window contains pixels from different fields and then adjust the averaging process. The goal is to preserve linear features and edges. The decision is based upon statistics (mean values) calculated over fixed and predefined windows (eventually, with varying shapes).

Image segmentation is the division of the image plan into disjoint regions. All the different approaches to image segmentation involve a decision process to determine if 2 adjacent pixels or sets of pixels are similar and should be put together (merged). The difference between the 2 mean values is often used. A segment is a set of connected pixels. We will consider only hierarchical or region growing approaches where segments are sequentially merged to form larger segments. We could initially start with each individual pixel as segment. We then sequentially take 2 adjacent segments and merge them if they are similar. The shapes and sizes of segment are not predefined. The segments grow and expand as the segmentation process progresses.

An important difference between filtering and segmentation is the selection of the pixel set used in calculation. In segmentation, the pixels are included into a segment as the result of decisions. When we calculate the mean value of a segment, we know that the used pixels have been found similar. In filtering, the calculation is performed over predefined windows and we do not know a priori if the pixels in the windows are similar. SAR adaptive filtering techniques try to select the most appropriate window among a set of alternatives. Hopefully, the selected window will contain similar pixels. Unfortunately, the decision often involves values calculated over windows that we do not know yet if they are homogenous.

2.3- The Gamma filter

Many SAR adaptive filters [3] use a weighted average of the pixel value I and the mean value $\bar{I}$ over a fixed size centered window:

$$\hat{R}(x,y) = w\,I(x,y) + (1-w)\,\bar{I}(x,y)$$

where $\hat{R}$ is the estimated ground reflectivity value and w is the weighting factor. Different filters use different formulas to calculate the weighting factor from the coefficient of variation estimated over the window. Near edges, the weighting factor should be close to 1 to preserve the initial value. Inside homogeneous fields, the value should be 0 to smooth out the noise. The Gamma filter [1] is similar but uses a more complex non-linear equation. The filter is used to smooth the image while preserving the linear features and the edges. It tries to detect image discontinuities and reduces smoothing to preserve edges. A 7x7 window is used. Figure 2 shows a 7-look airborne C/X SAR 580 image. There are large variations of pixel values between neighbor pixels. In the Gamma filter result, Figure 3, we have uniform surfaces inside fields. Near edges, the original pixel values are more preserved, evoiding the blurring of the edges. There are also many zones inside fields with large pixel value variations.

3- A region-growing "filter"

We propose a region-growing approach to define the set of pixels used in mean value or other parameter calculation. The definition of the pixel set or segment is performed independently and sequentially for each pixel. For each pixel, we first create a segment containing this only pixel. For each 4-neighbour pixel, we calculate its absolute difference with the initial pixel. The segment grows by including the neighbor pixel with the smallest difference. The list of neighbor pixels is updated after each merge. The merging continues until the segment size reaches a predefined stopping value. The mean value of the segment is calculated and assigned to the output pixel (segment starting point).

Figure 4 shows the result obtained when the region growing is applied to the SAR image of Figure 2. The region growing is stopped when the segment contains 30 pixels. This is not what we expect from a filtering process. There is no smooth image surface as in Figure 3. The process has replaced the speckle texture by a new type of texture where the range of the gray level values inside region is smaller. The formation of unconstrained shape segments results in the preservation of edges while reducing the smoothing aspect (because of the preservation of contrast on segment boundaries).
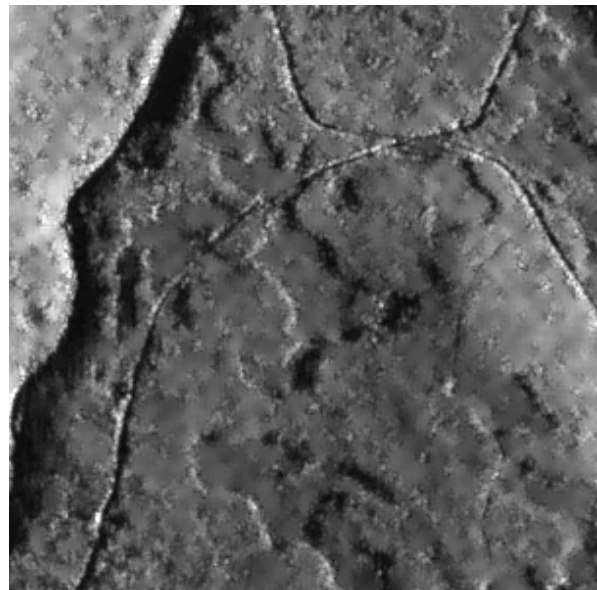

Figure 2: A 7-look 300x300 SAR image.

Figure 3: Gamma filter result (7x7 window).

Figure 4: Region growing "filter" result.

We do not consider that this region growing process could be used as a filter by itself. It should be used as a part of a more complete process. We are also interested by a modified version for extremum value reduction.

4- Reduction of extremum values

SAR images are characterized by speckle noise with large variance. They can be described as composed of alternating bright and dark spots. There is some similarity with salt-and-pepper noise (or impulse noise). The impulse noise could be viewed as outlier values that should be removed. The mean value of a set of pixels minimizes the mean-squared-error and will be greatly affected by outlier values. Therefore, median filter is more generally used with impulse noise [4]. Often, the median value could be used instead of the mean value. To calculate the median, we need to order the pixel values, witch is computer time consuming, and select the middle one. It is expected that the values in the middle of the list will be rather similar and that outliers will be located at both ends. A fair amount of outliers could be accepted without producing an incorrect median value. Median filter has been used for SAR images. When the processing window cover a homogeneous area, the mean value is a better estimate than the median.

The bright and dark spots of SAR images are not really outliers. They are values coming from both tails of the signal distribution. The large value range complicates the processing of the images. It is the purpose of image filtering to reduce the value range. However, this is a difficult task. We are considering the fact that image filtering should be easier if we could reduce the value range beforehand. To do so, we will consider only the value coming from both ends of the distribution. In the case of the median filter, those extreme values are replaced by the middle value of the ordered list. We are looking for a more limited modification. If the value is at the high end of the list, we could select the Mth lower value in the list. If the value is at the low end, we select a higher value.

The bright and dark spots correspond to local extrema. The reduction process will start only from these extrema. We also take advantage of spatial information by applying a region growing process from each of these extrema. If we start from a maximum (minimum) point, then all its neighbors will have a lower (higher) value. The region will grow by including the neighbor pixel with the highest (lowest) value. The merging process will stop when the segment (region) has reached the required size M. All the pixels inside the segment are replaced with the lowest (highest) value of the segment. We should use small value for the parameter M (2 to 5).
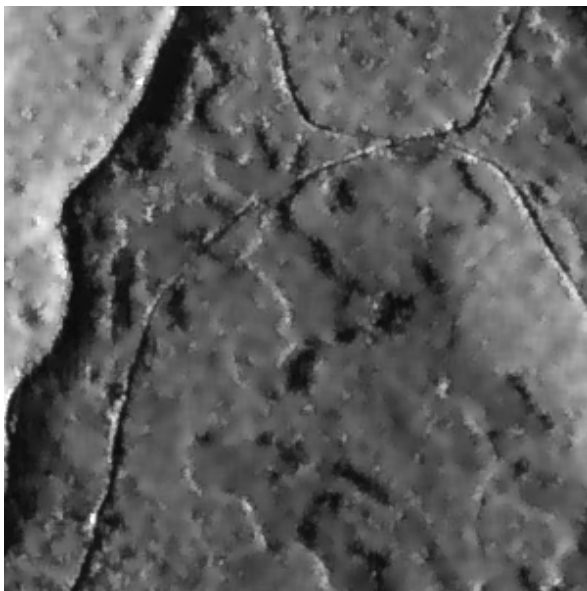
5- SAR image processing

The extremum reduction technique could be used as a pre-processing step for SAR image filtering and segmentation. This takes into account the probability information about the radar signal (rank statistics) and the spatial information (image field structures). The advantage of the process is illustrated by the filtering of a SAR image with and without pre-processing. For the extremum value reduction pre-processing, we use 3 pixel segments (M=3). Figure 2 shows the original SAR image with 7 looks and 300x300 pixels. Figure 3 shows the Gamma filter result. Figure 5 shows the result of the extremum reduction pre-processing step. It looks rather the same as the original image. Figure 6 shows the result of the Gamma filter applied to Figure 5. The pre-processing step contributes to improve the inside field smoothing.
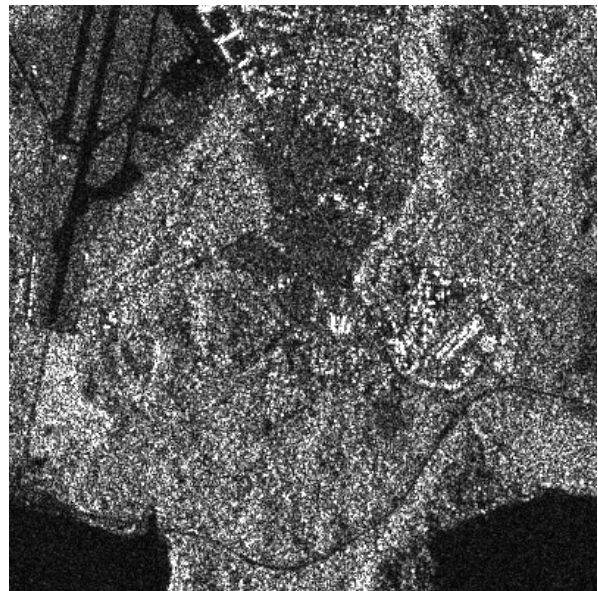
Figure 5: Extremum reduction result.
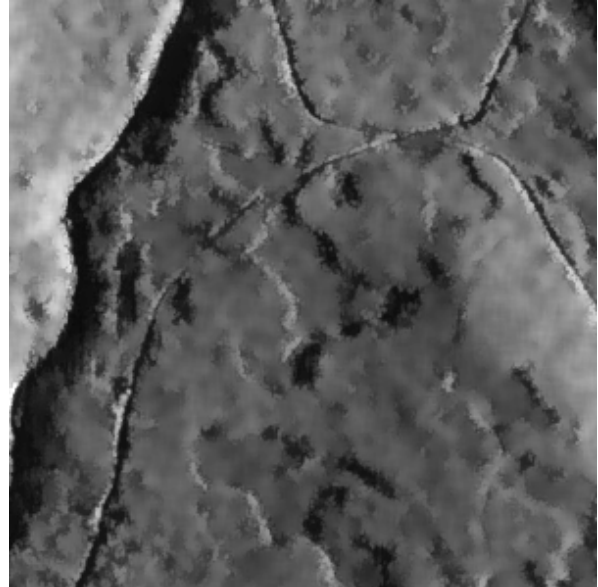
Figure 7: Region growing and Gamma filter.

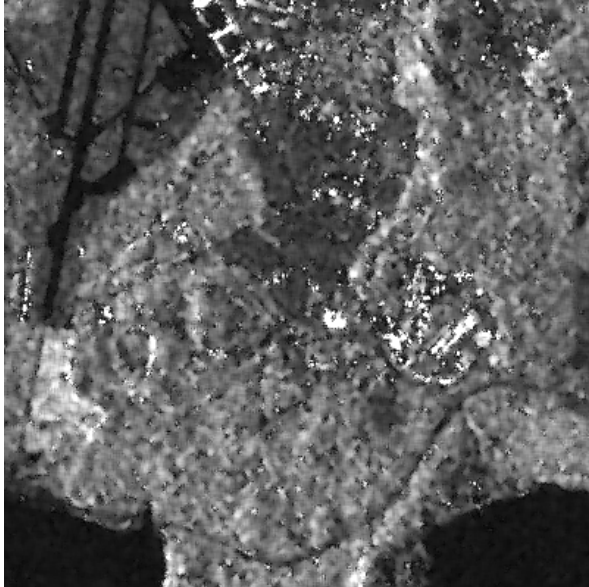*Figure 6: Extremum reduction and Gamma filter result.*

Figure 8: 1-look 400x400 Raradsat image.

The region growing process could also be used as a pre-processing step. Figure 7 shows the result of the Gamma filter applied to Figure 4. The 2 last figures show that the 2 segmentation-based processes could be useful to improve the smoothing of homogeneous areas. However, there is some deterioration of linear features and edges. Further studies are needed to assess the importance of this deterioration while taking into account the improvement of smoothing. As proposed in [3], the pre-processed image could be used to calculate the coefficient of variation only. The initial image is used for the calculation of the output mean value of the adaptive filter.

The following figures show the results for a 1-look SAR image where the noise variance is larger. Figure 8 is the original 1-look 400x400 Radarsat fine mode image. Figure 9 shows the Gamma filter result (5x5 window). Figure 10 shows the Gamma filter result after extremum reduction (M=3) and Figure 12 after region growing (M=10). The pre-processing step contributes to improve the inside field smoothing.
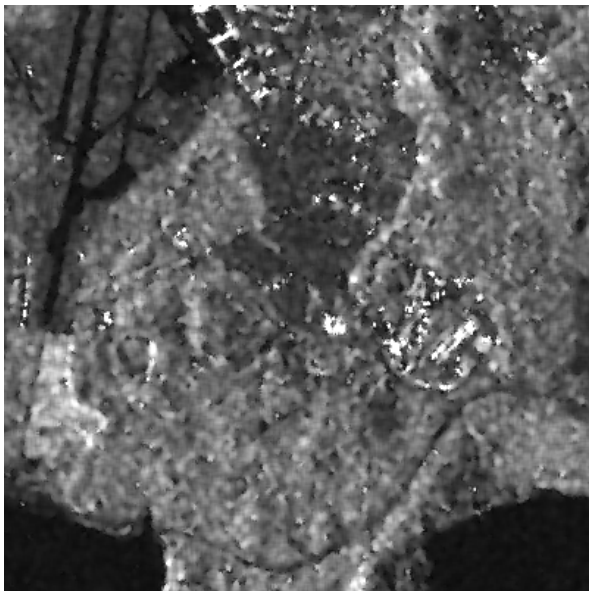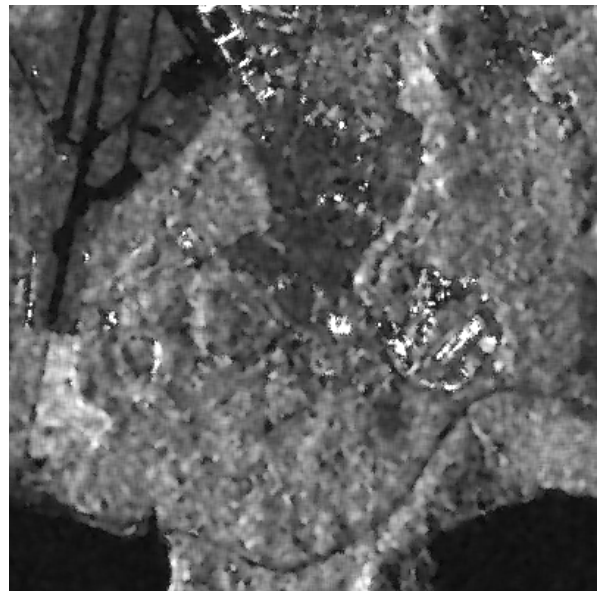
Figure 9: Gamma filter result.

Figure 11: Region growing result (M=30).

Figure 10: Extremum reduction and Gamma filter result.

Figure 12: Region growing and Gamma filter result.

Evaluation of SAR image filters is a complex topic [5]. We have used synthetic images to analyze the effect of filters on edges (field boundaries). 4-look images with 2 regions are produced. The left region has a mean value of 1 and the right region a mean value of 4 or 8. The top row of *Figure 13* shows the value distributions inside each region. A 5x5 window is used. The 2nd row shows the distributions of the filtered values at 3 column from the edge where the window covers only one of the 2 regions. The next row, at 2 column from the edge where the window includes one column (among 5) from the other region, and the last row, next to the edge where 2 columns of the window are inside the opposite region. The smoothing corresponds to the reduction of the width of the distribution. The edge is blurred if the mean value (the center) of the distribution is shifted. The adaptive nature of the Gamma filter means that the smoothing is reduced as we get closer to the edge. There is a shifting of the value inside the right region only (mean of 4 or 8). The

utilization of an extremum reduction pre-processing step results into more smoothing (thinner distributions). The mean value of the right region is not displaced while there is a small displacement for the left region.

6- Conclusion

Image filtering and segmentation are basically two different approaches to image processing. We have presented 2 segmentation–based techniques that could be useful as a pre-processing step in SAR image filtering, a region growing "filter" and an extremum reduction process. Appropriately adapted filtering techniques could also be useful as pre-processing step to SAR image segmentation.

Acknowledgements

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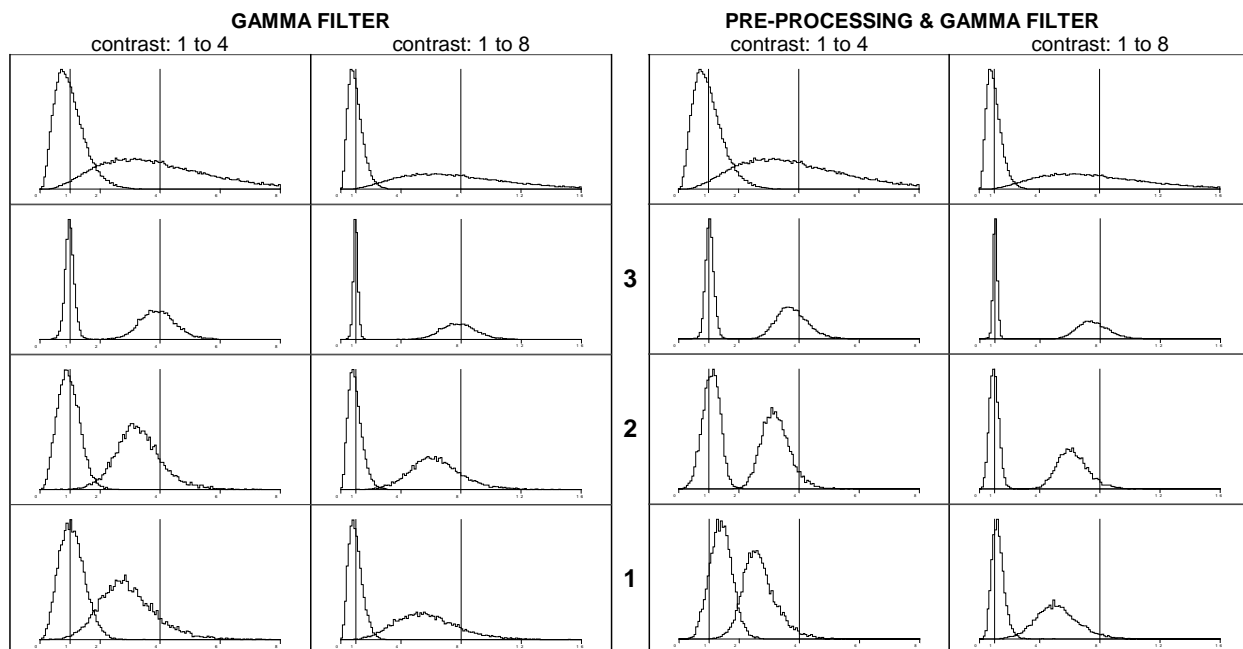

Figure 13: Signal probability distributions before and after filtering.