Radiometric and Spatial Aspects of Speckle Filtering

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This article reports on a comparative study of more than 30 different speckle filters, based on quantitative performance measures as well as visual criteria. Both radiometric and spatial aspects of the filtering problem are analyzed. We propose an improved method for local structure detection in speckle filters.

INTRODUCTION

A speckle filter estimates the reflectivity of a given pixel based on its intensity and the intensities of a set of neighboring pixels. It can be considered as a combination of a radiometric estimator and a method to define the relevant neighborhood. Several radiometric criteria have been proposed, based on different optimization criteria. While the first speckle filters computed local statistics on a fixed size sliding window, refined versions include local detection of structures or homogeneous zones. Filters based on modern concepts such as Markov random fields and wavelets have also been proposed. It is generally admitted that a speckle filter should substantially reduce the speckle in zones of constant radar reflectivity, while preserving the structures and textures of the image, in order to facilitate subsequent visual inspection or automatic analysis.

METHODS

We have tested more than 30 different combinations of estimators and neighborhood types [1]. The basic estimators that we have considered are:

- the Kuan filter, which is a linear minimum mean square error (LMMSE) estimator [2].
- the Frost filter, which is a Wiener filter adapted to multiplicative noise [3].
- the improved Frost filter proposed by Touzi [4].
- the maximum a posteriori (MAP) filter, which supposes Gamma distributed texture and speckle [5].
- the a posteriori mean (APM) filter, which also is based on the hypothesis of Gamma distributed texture and speckle [6].
- the T-linear filter, which is an approximation of the APM [7], here with T=0.5.

Each of these estimators has been associated with different ways of defining the neighborhood on which the local statistics are computed:

- fixed size analyzing window without structure detection.
- detection of the biggest homogeneous zone within the analyzing window which includes the central pixel. A zone is considered to be homogeneous if the measured coefficient of variation is below a certain threshold.
- analyzing window with local structure detection based on the generalized likelihood ratio [8], which constitutes an improvement of the method based on the ratio detector described in [5] in the general case where the analyzing window is split in two unequally sized parts (asymmetrical binary masks).
- intersection between a fixed size analyzing window and a region defined by a segmentation [9].
- entire regions defined by a segmentation [9].

We have defined altogether 42 directional binary masks representing edges, lines and point targets, which are used both for local structure detection and to identify maximum size homogeneous zones. As far as the homogeneity criterion is concerned, the threshold for the coefficient of variation is here set to the inverse of the square root of the equivalent number of independent looks of the image. The detection threshold for the generalized likelihood ratio corresponds to a probability of false alarm (PFA) of the order of 10^{-5} for each mask. The total PFA (for all the masks tested) is of course much higher. The segmentation used by some of the filters is in this study obtained with the SARSEG segmentation scheme [10]. It should be noted that there is no region-based version of the Frost filter.

The results obtained with a selection of recent filters, created and implemented by other research teams, were also included in our study:

- the MAP filter of Wu and Maître (ENST), which detects maximum size homogeneous zones through region merging [11].
- the model-based despeckling (MBD) filter of Walessa and Datcu (DLR), which is based on Bayesian inference and Gauss-Markov random fields [12].
- the distribution entropy MAP filter of Nezry (Privateers) [13].
- the multiresolution filter of Touzi (CCRS) [14].

Numerous other filters merit to be tested, but they were unfortunately not available to us in the framework of this project.

RESULTS

All the methods described above have been applied to a simulated single-look SAR image, as well as to single-look and multi-look ERS-1 images. For the simulated SAR image, the mean square error could be calculated, as the ideal image is known. For the real images, the statistics of the ratio image, obtained by computing the ratio between the original image and the filtered one pixel by pixel, were compared to the statistics of fully developed speckle [15]. In addition to these quantitative measures, much weight was given to the visual aspect of the filtered images in terms of speckle reduction and preservation of structures.

All filtered images, ratio images and quantitative results are given in [1]. Some examples of filtered images are shown in Fig. 1. The following observations were made:

- Among the filters which use a fixed size analyzing window without detection, the Frost filter seems to better choice, as it takes the presence of edges into account through negative exponential weighting of the intensities as a function of the distance to the central pixel. The other estimators yield blurred filtered images. It should be noted that the differences between the estimators diminish when the number of looks increases.
- The results are considerably improved by local detection of structures or homogeneous zones. In this case, the best results are obtained with the APM, T-linear and MAP estimators. The APM and T-linear estimators are unbiased and generally produce the most precise estimate of the radar reflectivity in homogeneous

zones. The MAP is slightly biased, but it preserves textures and fine structures particularly well, and is thus better suited for visual interpretation.

- Optimal structure detection based on the generalized likelihood ratio seems to perform better than detection of homogenous zones, notably with respect to the preservation of fine structures. The MAP filter of Wu and Maître, which uses region growing to identify the biggest homogeneous zone around the pixel to be filtered, yields and intermediate result.
- The choice of the number of binary masks for the detection is delicate: the higher the number of masks, the higher the probability of detection (PD), but the false alarm rate (PFA) increases as well. The latter phenomenon rapidly become dominant. This illustrates the limitations of this approach: due to the speckle, we have to use big analyzing windows (typically between 7×7 and 13×13), in which case the number of possible spatial configurations becomes extremely high, but we have to restrict the number of masks to keep the overall PFA on an acceptable level. 42 masks was found to be a good compromise in this study.
- The region-based filters, relying on a prior segmentation, are not as good as the versions based on local structure detection when filtering single date images, as in the present study. However, a region-based version of the vectorial LMMSE filter [10] yields excellent results for temporal series of SAR images, in particular as far as the preservation of textures and structures are concerned, thus enabling improved multitemporal classification. The regions generally contain an important number of pixels, permitting a very precise estimation of the intercovariance matrices used by the vectorial MMSE filter.
- The methods based on Markov random fields work on a relatively small neighborhood (typically 3×3 or 5×5), but in an iterative manner. In this way, both precise estimation of the radar reflectivity and good spatial adaptability can be obtained. The MBD filter of Walessa and Datcu combines excellent preservation of structures with strong smoothing in homogeneous zones. The new filters of Nezry and Touzi also demonstrate good structure detection capabilities, but the zones supposed to be homogeneous are less smoothed than with the MBD filter or with our MAP filter with optimal structure detection.

Depending on the tuning of the parameters, the results could converge or diverge more than in our study. For other sensors or scene types, the relative performances could also be different. Single-look images are the most difficult to filter, in particular when a limited spatial resolution (as in the case of satelliteborne sensors) leads to narrow structures that are very difficult to detect. The results obtained on single-look images vary a lot from one filter to another, and none of the tested filters yields completely satisfactory results.

CONCLUSION

The comparative study reveals interesting differences between the radiometric estimators employed by different adaptive speckle filters. However, the method used to determine the relevant neighborhood seems to play an even more important role. We propose to use local structure detection based on the optimal generalized likelihood ratio.

All adaptive speckle filters perform automatic analysis of the image and may introduce artifacts which complicate subsequent automatic analysis or visual interpretation. Direct automatic analysis with robust methods which take the speckle statistics explicitly into account, or dedicated interactive visualization tools based on non-adaptive transformations of the image (e.g. different spectral weighting functions), can be better than speckle filtering for many applications.

The radar division of the French Space Agency CNES (CNES/DSO/OT/QTIS/SR) intends to continue the comparison of speckle filters on a larger scale. Both a set of SAR images and the corresponding filtered images will be made available on CD-ROM (possibly also over the Internet). Hence different research groups can test their speckle filters on the same images, submit their results, and compare them to the other filtered images. Contact Frédéric Adragna (Frederic.Adragna@cnes.fr) for more information.

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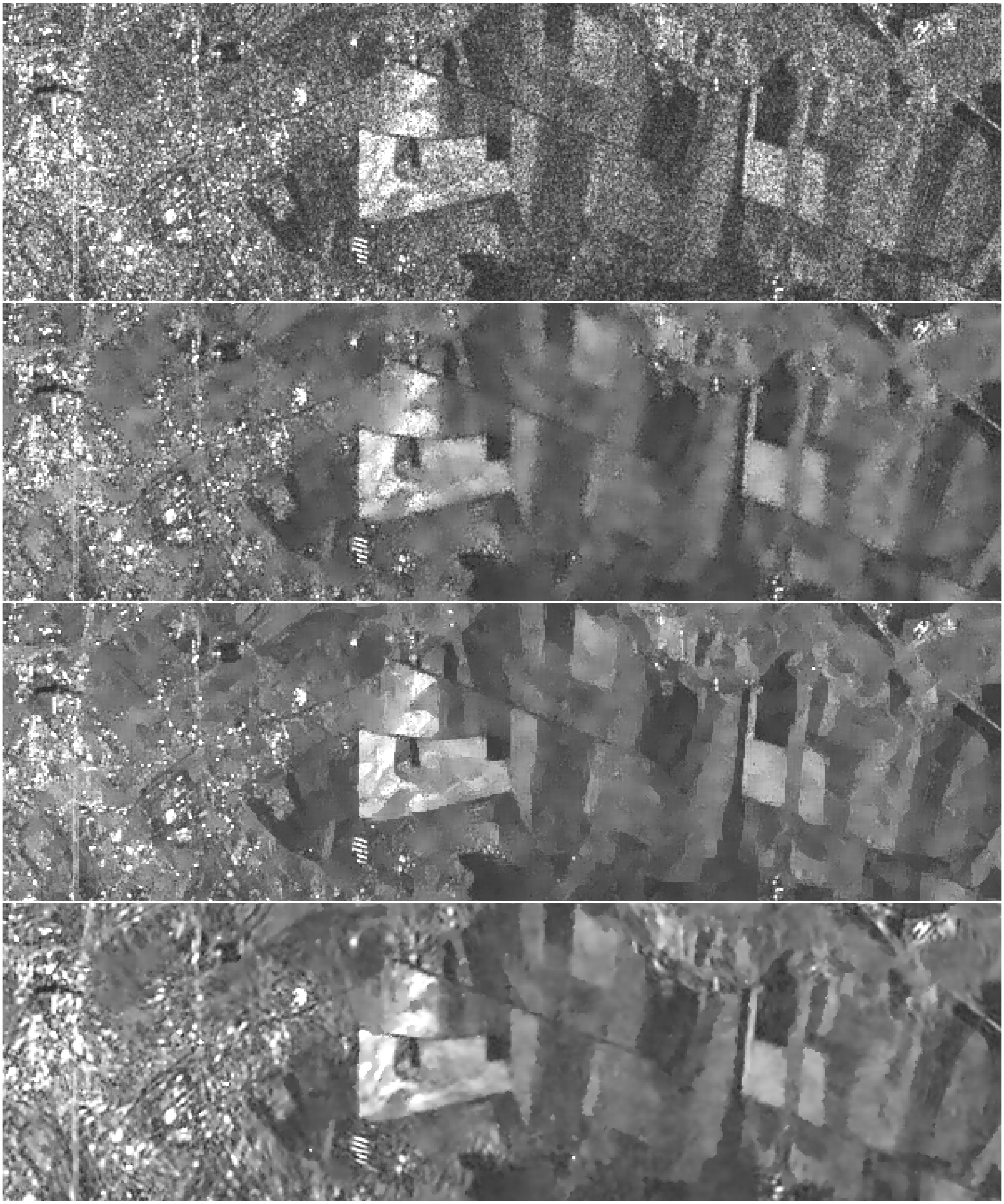

Figure 1. a) Original 4-look ERS-1 image of Bourges, France. © ESA – ERS-1 data – 1993. Distribution SPOT Image. Filtered images obtained with b) the 9 × 9 MAP filter without detection, c) the 9 × 9 MAP filter with optimal structure detection, and d) the MBD filter.