Radar Imagery Filtering with Use of the Mathematical Morphology Operations

P. Kupidura*, P. Koza**

Faculty of Geodesy and Cartography, Warsaw University of Technology, Pl. Politechniki 1, 00-785, Warsaw, Poland

Abstract

This paper concerns the application of mathematical morphology operations for suppression of speckle from radar satellite images. Different traditional widely-used filters are compared with the morphological alternate filters, especially with the filter with multiple structuring function. The comprehensive comparison of the traditional filters is presented, as well as the background on mathematical morphology and morphological filters. Then the evaluation of compared filters applied on TerraSAR-X images is presented.

Keywords: radar imagery, filtering, mathematical morphology, speckle noise.

Introduction

15th of June 2007, the new radar satellite – TerraSAR-X has been placed in the orbit of the Earth. Due to its innovative technology it seems to open the new chapter in Earth imagery from the cosmic space. The most important TerraSAR-X images attributes are:

• very high spatial resolution (from 1m to 16m),
• several variants of polarization of emitted and detected signal,
• high temporal resolution (each 2.5 – 4.5 days, with no weather restrictions).

The launching of the twin satellite TanDEM-X and creating of interferential base of these satellites is also planned. This all causes radar imagery and radar images processing the more and more important part of the remote sensing.

Synthetic Aperture Radar (SAR) imagery is an useful tool for collection of data about Earth’s surface. However, radar images are inherently corrupted by speckle, significantly decreasing their quality what appears, among other things, in reducing the accuracy of automated classification [1, 2]. Although from the physical point of view, speckle is the result of interactions between scatterers inside a pixel at the sub pixel level and therefore, the speckle pattern should reflect the conditions of ground surface [2], the reduction of the speckle is one of the most important processes to increase the quality of radar images.

Most commonly used speckle filters have good speckle-smoothing capabilities, however their capabilities for detail preservation, what is the second key issue in speckle filtering, are limited [3]. Therefore, the proposal of the application of morphological filters for that purpose is presented.

Brief Description of Filters used in the Tests

Non-Morphological Filters

Several commonly used speckle filters are briefly described below:

Mean Filter – a very simple filter averaging pixel values in the kernel. It does not remove the noise, but blurs it over the neighborhood pixels. The less satisfactory method of the speckle suppression.

Median Filter – also a simple one, returns a median value of the neighborhood defined by the kernel. Efficiently reduces such erratic variations like low-valued and high-valued pixels, corresponding to deconstructive and constructive speckle.

Lee and Lee-Sigma Filters – assume Gaussian distribution for the noise. Filters use the statistical distribution of the DNs (Digital Numbers) within the kernel to estimate the value of the pixel of interest. For further information about Lee and Lee-Sigma filters, reader is referred to, respectively [4, 5].

* e-mail: p.kupidura@gik.pw.edu.pl
** e-mail: p.koza@wp.pl
Frost Filter – like Lee filter, based on local statistics and multiplicative model. Firstly, it detects the edges in the image and averages less in the places where the edges are found to preserve them (Frost et al., 1982).

Local Region Filter – divides the kernel into eight regions based on angular positions and calculates the variance for each region and replaces the pixel of interest by the mean of the pixel values of the region of the lowest variance value.

Gamma-MAP Filter – the Maximum A Posteriori Filter, based on a multiplicative noise model. An adaptive speckle filter, tending to maximize a posteriori probability of the original signal from the speckle signal (Frost et al., 1982)

All of the filters, briefly presented above were used to help to estimate the effectiveness of the morphological filters.

Morphological filtering

Morphological filters base on a simple idea of alternating two operations: opening and closing, removing, respectively, small high-valued and low-valued objects from the image. These filters, called generally alternate filters differ from each other in the type of opening and closing operations applied. Below, three morphological filters are briefly presented:

Alternate Filters – the sequence of basic opening and closing. The simplest of the morphological filters, effectively remove the noise but also blur the image, by removing most of the edges of the objects. They are often called OC (opening followed by closing) and CO (closing followed by opening).

![Fig. 1.](image-url) a) original image (RGB VV-VH-VV) and classification of images filtered using: b) Median Filter, c) Lee-Sigma Filter, d) Frost Filter, e) Alternate Filter, f) Multiple Structuring Element Filter. Light and dark blue - water, light and dark green - vegetation, yellow and brown - soil, light and dark grey - buildings.
Alternate Filters with Multiple Structuring Function (Element) – the sequences of opening and closing operations with multiple structuring element. It removes the small objects from the image but preserves edges and linear objects.

The reader is referred also to the books and articles of mathematical morphology and morphological filtering for an extended background on this subject [7-15].

Test image and methodology

The imagery used for testing was a TerraSAR-X image taken on 27th of November 2007 from the environs of Kozienice, the town situated ca. 50 km to the South-East from Warsaw, capital city of Poland. Pixel size was 4,75m x 4,75m, polarization of two types (VV and VH) and orthorectification has been applied using SRTM.

Filters were tested basing on similarity between the results of classification of filtered image and a reference image created in visual interpretation process. Eight classes has been extracted: two classes of water, two classes of vegetation, two classes of bare soil and two classes of buildings. The signatures for each of the classes have been defined once for all classification processes on speckle-free parts of the original image to assure the same conditions for all filtering results. A Mahalanobis distance method was applied using Erdas IMAGINE 9.1. After classification, classes of the same type have been aggregated.

Fig. 1 presents a part of the original test image and classification of the images filtered using chosen operations.

As mentioned before, both, noise suppression and detail preservation are the key issues for filtering. For the evaluation of the second issue a manual digitalization has been done using certain parts of filtered images. Results of this process have been compared to the result of the digitalization of the original image. The testing image for this evaluation has been indicated in heterogeneous, built-up part of the original image. The objects in such an area are relatively small so they can be easily removed by filters. Degree of the preservation of the structure of the original image was a rate of the filter in this part of the testing.

At last, the visual analysis of the filtering results have been applied. Conclusions of that analysis are also a part of the filters evaluation.

Two types of morphological filters were tested: simple Alternate Filters (AF) and Alternate Filters with Multiple Structuring Function (MSF). These filters were tested comparing to all non-morphological filters described above in this paper. Non-morphological filters were applied using Erdas IMAGINE 9.1 software, while morphological filters – using free downloadable (via Internet) software Morpho 1.2.

All filters were applied using two different sizes of the kernel (structuring element): 5x5 and 11x11 pixels.

Experimental results

Firstly the results of the classification of the image has been evaluated. The first observation is, that the best results have been obtained using the bigger moving kernel (structuring element) – 11x11 pixels so the results of filtering using these kinds of filters are presented in below.

The best precision was obtained for the image filtered using a simple Alternate Filter. The reason is its capability to removing the objects smaller than the size of the structuring element. The specificity of the speckle in the radar images allows this type of operation to suppress effectively the noise. The best non-morphological filter in this evaluation is a Median Filter. This filter allows to remove the isolated low-valued or high valued pixels. The second morphological filter – MSF results are also satisfying, but not as good as AF results. However, its quality is comparable to other non-morphological filters. The reason of the difference between two morphological filters is that the MSF filter preserves linear structures in the image. In some situations, noised pixels can create structures of this type – irremovable by MSF filter but easily removable by AF filter. Surprisingly good effort has been showed by a Mean Filter. This can be, however, the result of relatively big and homogeneous test areas, without a significant number of details. Generally, the results of filtering using different types of operation are relatively similar, what probably means, that all of the tested filters are more or less effective for speckle suppression.

However, the evaluation presented in the Table 1 shows only the first key issue of filtering - noise removing. The second one is a detail preservation and it can be tested by

Table 1: Precision of classification of the images filtered using different types of operations

<table>
<thead>
<tr>
<th>Filtering type</th>
<th>Water</th>
<th>Vegetation</th>
<th>Soil</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-filtered</td>
<td>91.03</td>
<td>65.22</td>
<td>73.76</td>
<td>76.7</td>
</tr>
<tr>
<td>AF</td>
<td>97.59</td>
<td>97.82</td>
<td>86.08</td>
<td>93.8</td>
</tr>
<tr>
<td>Median</td>
<td>95.45</td>
<td>85.91</td>
<td>94.53</td>
<td>92.0</td>
</tr>
<tr>
<td>Lee-Sigma</td>
<td>94.81</td>
<td>86.34</td>
<td>93.6</td>
<td>91.6</td>
</tr>
<tr>
<td>Gamma-MAP</td>
<td>97.42</td>
<td>76.16</td>
<td>96.95</td>
<td>90.2</td>
</tr>
<tr>
<td>Mean</td>
<td>89.75</td>
<td>86.00</td>
<td>94.01</td>
<td>89.9</td>
</tr>
<tr>
<td>MSF</td>
<td>95.61</td>
<td>80.86</td>
<td>91.48</td>
<td>89.3</td>
</tr>
<tr>
<td>Local Region</td>
<td>95.78</td>
<td>80.93</td>
<td>89.87</td>
<td>88.9</td>
</tr>
</tbody>
</table>
Table 2. The results of the detail preservation testing – precision of digitalization on filtered images

<table>
<thead>
<tr>
<th>Filtering type</th>
<th>Precision of digitalization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frost</td>
<td>85.6</td>
</tr>
<tr>
<td>MSF</td>
<td>85.3</td>
</tr>
<tr>
<td>Gamma-Map</td>
<td>85.1</td>
</tr>
<tr>
<td>Lee-Sigma</td>
<td>63.6</td>
</tr>
<tr>
<td>Local Region</td>
<td>63.5</td>
</tr>
<tr>
<td>Mean</td>
<td>63.1</td>
</tr>
<tr>
<td>Median</td>
<td>58.4</td>
</tr>
<tr>
<td>AF</td>
<td>57.6</td>
</tr>
</tbody>
</table>

evaluating the quality of classifications only in the edges of the objects in the image. This evaluation, realized as described in the previous section, is presented in the table 2.

The results presented in the table 2 show, that Alternate Filter with Multiple Structuring Function (MSF) assures the detail preservation comparable to the best non-morphological filters: Frost Filter and Gamma-MAP Filter. On the contrary, Alternate Filter (AF), the best in the previous evaluation, has unsatisfying precision in this matter. It means, that, removing the noise, this filter removes also the edges of the objects in the image. So it is not capable to distinguish the noise from the edge, what is an important issue of an effective filter. The results of the filtering using other, non-morphological filters, like Median, Lee-Sigma or Mean are comparable.

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Fig. 2 a) original image (RGB VV-VH-VV) and images after filtrations using: b) Median Filter, c) Lee-Sigma Filter, d) Frost Filter, e) Local Region Filter, f) Gamma-MAP Filter, g) Alternate Filter, h) Multiple Structuring Function Filter.
Figure 2 presents the part of the radar scene used for the evaluation of detail preservation. In the original, non-filtered image buildings can be clearly seen (geometrical, very bright objects). Using Alternate Filter these objects have been almost completely removed. The circular structure can be seen instead. It is caused by the shape and the size of the circular structuring element. The second morphological filter gives the image of a much higher quality. As the results presented in the table 2 show, the detail preservation is its strength. However, the image obtained using this filter differs from other filters with good detail preservation factor: Frost Filter and Gamma-MAP Filter. Two non-morphological filters rather blur the objects, while MSF Filter removes smaller objects but leaves bigger objects “untouched”. It means that it preserves edges of the objects in the image better than these two filters when the objects are not smaller than the structuring element used in filtration. Smaller objects are treated as the noise and almost completely removed from the image.

Conclusions

The realized tests showed that Alternate Filter with Multiple Structuring Function is an efficient speckle filter. Its capability of removing the noise from the radar image is comparable to other, commonly-used, non-morphological filters, like Frost, Lee-Sigma, Gamma-MAP or Median. Generally, all of the tested filters showed a comparable efficiency for the noise suppression, however, it can be caused, among other things, by significant spectral width of the extracted classes. In this case, more important was their capability to detail preservation. Also in this matter MSF Filter showed a very high effectiveness, comparable to the best non morphological filters like Frost and Gamma-MAP. Additionally, the visual analysis of the results showed, that image filtered by MSF Filter, keeps its sharpness, differently than the images blurred by other filters. It can improve a visual interpretation of the image. Another advantage of the MSF Filter is, that it can be applied using BlueNote, free software, downloadable via Internet.

All arguments presented above show, that the morphological Alternate Filter with Multiple Structuring Function (MSF) is and interesting operator which can be as well used for speckle suppression in the radar imagery, as the others commonly-used speckle filters.

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References