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THE MORPHOLOGICAL FILTERING OF THE REMOTE SENSING IMAGES FOR THE NOISE REDUCTION COMPARING TO TRADITIONAL FILTERS

EFEKTYWNOŚĆ FILTRACJI MORFOLOGICZNEJ OBRAZÓW SATELITARNYCH I LOTNICZYCH W ZAKRESIE REDUKCJI SZUMÓW W PORÓWNANIU DO TRADYCYJNEJ FILTRACJI CYFROWEJ

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Introduction

The advantages and disadvantages of the traditional (non-morphological) filters are commonly known. Focusing only on disadvantages, it is necessary to mention that most of these filters mainly blur noise over the image, making it less visible. That operation causes depreciation of the amount of information on the image rather than increasing its quality.

In recent years there has been a trend to develop more efficient procedures for improving image quality. Theoretically, morphological filters have potential in such usage without possessing the drawbacks of traditional filters.

The purpose of this paper is to present the results of an evaluation of the chosen morphological filters in comparison to the non-morphological ones. To achieve this non-morphological filtering was applied as a reference and objective indicators were used.

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 least satisfactory method of speckle suppression.

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

The filters briefly described above were used to help to estimate the effectiveness of the morphological filters.

Basics of mathematical morphology and morphological filtering

Mathematical morphology is a set theory approach, developed by J.Serra and G. Matheron. It provides an approach to process digital images based on their geometrical shape.

Two fundamental morphological operations – erosion and dilation are based on Minkowski operations. There are two different types of notations for these operations: Serra/Matheron notation and Haralick/Sternberg notation. In this paper Haralick/Sternberg notation, which is probably more often used in practical applications, is used. In this notation erosion is defined as follows (Serra, 1982):

$$\varepsilon_B(X) \bigcap_{y \in B} X_y$$

and dilation as:

$$\delta_B(X) = \bigcup_{y \in B} X_y$$

where: *B* is a structuring element and $X_y = \{x + y : x \in X\}$

Two other principal operations called opening and closing are simple sequences of erosion and dilation operations. Opening is defined by the following equation:

$$\gamma_B(X) = \delta_B(\varepsilon_B(X))$$

and closing as:

$$\varphi_B(X) = \varepsilon_B(\delta_B(X))$$

There are other morphological operations important for the experiments presented in this paper. They are called opening and closing with multiple structuring element (function) and are defined as follows (Stevenson, Arce, 1987; Song, Delp, 1990):

$$\gamma_G(X) = \max_{B^k \in G} \left(\gamma_{B^k}(X)\right)$$

$$\varphi_G(X) = \min_{B^k \in G} \left(\varphi_{B^k}(X)\right)$$

where is a set of the structuring elements. The exemple of such a group is presented below:

$$B^1 = \begin{bmatrix} 0 & 0 & 0 \\ 1 & \underline{1} & 1 \\ 0 & 0 & 0 \end{bmatrix}, \quad B^2 = \begin{bmatrix} 0 & 1 & 0 \\ 0 & \underline{1} & 0 \\ 0 & 1 & 0 \end{bmatrix} \quad B^3 = \begin{bmatrix} 0 & 0 & 1 \\ 0 & \underline{1} & 0 \\ 1 & 0 & 0 \end{bmatrix} \quad B^4 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \underline{1} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Using these operations permits the removal of small objects from the image whilst preserving thin but long objects, e.g. the edges of bigger objects or other types of the objects of this type, like rivers, roads etc. As written above, mathematical morphology is a set theory approach, so it cannot be applied to gray-scale and colour images directly. In this case these operations may be applied using a 3D representation of gray-scale image called umbra, a latin term used in astronomy which means a shade appearing when a star light is covered by another orb. In a mathematical sense we define an umbra as follows (Sternberg, 1986; Nieniewski, 1998):

$$U(f) = \{(x,t) \in \mathbf{R}^2 \times \mathbf{R} : f(x) \geq t\}$$

Umbra of the gray-scale image is a 3D binary set and mathematical morphology operators can be easily applied using an umbra of a structuring element.

The reader is referred to the literature on mathematical morphology for an extended discussion concerning morphological operators (especially Serra, 1982; Haralick et al., 1987; Nieniewski, 1998; Kupidura, 2006).

Morphological filtering

Morphological filters are based on a simple idea of alternating two operations: opening, removing small high-valued objects and closing, removing low-valued pixels. 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 operations. 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).
- **ASF** – Alternate Sequential Filters – this type of filter has been described by (Sternberg, 1986), (Serra, 1988) and (Heijmans, 1994). They consist of using the sequence of bigger and bigger instead of one big structuring element (e.g. 3x3 pixels followed by 5x5 pixels instead 5x5 pixels applied directly on the image) what is supposed to preserve the structure of the image better than the simple alternate filters.
- **Alternate Filters with Multiple Structuring Function (Element)** – the sequences of opening and closing operations with a multiple structuring element. It removes the small objects from the image but preserves edges and linear objects.

The reader is referred also to the literature on mathematical morphology for an extended discussion of morphological filtering (especially Sternberg, 1986; Serra, 1988; Heijmans, 1994; Song, Delp, 1990; Kupidura, 2006; Jakubiak, 2008).

Filters comparison

The following tests were performed on grey scale aerial photos and the panchromatic satellite images, which were chosen because of their high quality. Image quality was deteriorated on purpose with the introduction of fake noise, such as Gaussian and ‘salt and pepper’. Thanks to such methodology there was the opportunity to use several indicators like Signal-to-Noise Ratio, Peak Signal-to-Noise Ratio, Root Mean Square Error, Mean Absolute Error and correlation coefficient. Applying the above coefficients allowed an objective analysis and evaluation of the considered filters. All indicators were calculated in ImageJ software. Filtration was performed in well-known commerce software like IDRISI32, ERDAS and also in Morpho (dedicated software made by Warsaw University of Technology).

Figure 1 shows parts of the tested images, which were chosen as the best result for each used filter for Gaussian noise (Table 1). There is still a small amount of noise in those parts of the image which confirms that neither of the applied filters were able to remove all the noise without changing error free pixels. Considering only filters able to preserve edges, we could place Alternate Filters with Multiple Structuring Function with size 11x11 and Frost Filter in this group. The results look different if the mean of coefficients is compared. Of such cases a median filter with 3x3 window is considered to be the best one. It is worth mention that this finding is a compromise between effectiveness in noise removing and edge preserving because this filter does not give an impressive effect in conserving the edges in the images.

Figure 2 shows parts of the tested images which were chosen as the best results for each filter used for ‘salt and pepper’ noise (Table 2). For this noise the effectiveness of the methods used in edge conserving was not tested. Exactly as for the previous noise no filter can be classified as being perfect. Considering only the result of noise removal, thr Median Filter with 3x3 kernel and Alternate Filters with Multiple Structuring Function 11x11 were found the best. On the image with applied simple Alternative Filter, we can observe that the noise is removed, but the structure of the image, especially on the edges of the objects, is significantly changed. This is the influence of a structuring element. This phenomenon is not seen in the image filtered by a Filter with Multiple Structuring Function because of its capability of detection and preservation of the edges in the image.

Table 1. Average value of correlation coefficient for all image and edges for the Gaussian noise

Kernel size / Structuring Function	Frost Filter	Alternate Filter	Alternate Filters with Multiple Structuring Function	Mean Filter	Median Filter	Median Sequential Filter
3x3	0.536	**0.580**	0.605	**0.614**	**0.616**	**0.616**
5x5	0.536	0.535	0.600	0.535	0.524	0.615
7x7	0.552	0.501	**0.610**	0.496	0.543	0.606
9x9	0.561	0.480	0.569	0.462	0.519	0.601
11x11	**0.567**	0.472	0.574	0.444	0.503	0.598

Table 2. Average value of correlation coefficient for all image and edges for the 'salt and pepper' noise

Kernel size / Structuring Function	Frost Filter	Alternate Filter	Alternate Filters with Multiple Structuring Function	Mean Filter	Median Filter	Median Sequential Filter
3x3	0.487	**0.966**	**0.972**	0.861	**0.976**	0.976
5x5	0.496	0.921	0.968	0.862	0.937	**0.972**
7x7	0.502	0.845	0.971	**0.875**	0.942	0.967
9x9	0.515	0.425	0.952	0.873	0.927	0.964
11x11	**0.525**	0.225	0.952	0.865	0.908	0.961

Conclusion

This research has shown that mathematical morphology has a significant potential in increasing image quality by filtering. In this test the Alternate Filters with Multiple Structuring Function appeared to be the most universal filter. It is a very important attribute because of the complication of noise in the image. The most important advantage of this filter is the effectiveness in noise reduction and very good edge preservation, as is shown in the two figures. Another morphological filter – simple Alternate Filter gives a relatively good results in noise reduction, but also causes significant changes to the structure of the filtered image, so cannot be recommended as a proper choice for filtering remote sensing data.

The other main deduction is that the correct identification of noise and the choice of this kind of filter influenced the results of the quality enhancement. It is because there is no one filter that would remove each noise with the same satisfied effect.

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Abstract

Niniejszy artykuł prezentuje wyniki badań przeprowadzonych nad użytecznością przetworzeń morfologicznych do redukcji szumów na wysoko rozdzielczych zdjęciach lotniczych i satelitarnych. Porównanie efektów filtracji z wykorzystaniem tradycyjnych filtrów z filtracją morfologiczną zostało oparte o znane współczynniki, powszechnie używane do pomiaru jakości sygnały. Badania dowiodły, że filtracja z wykorzystaniem operacji morfologii matematycznej powoduje lepsze usuwanie szumów z jednoczesnym lepszym zachowaniem wierności krawędzi niż tradycyjna filtracja.

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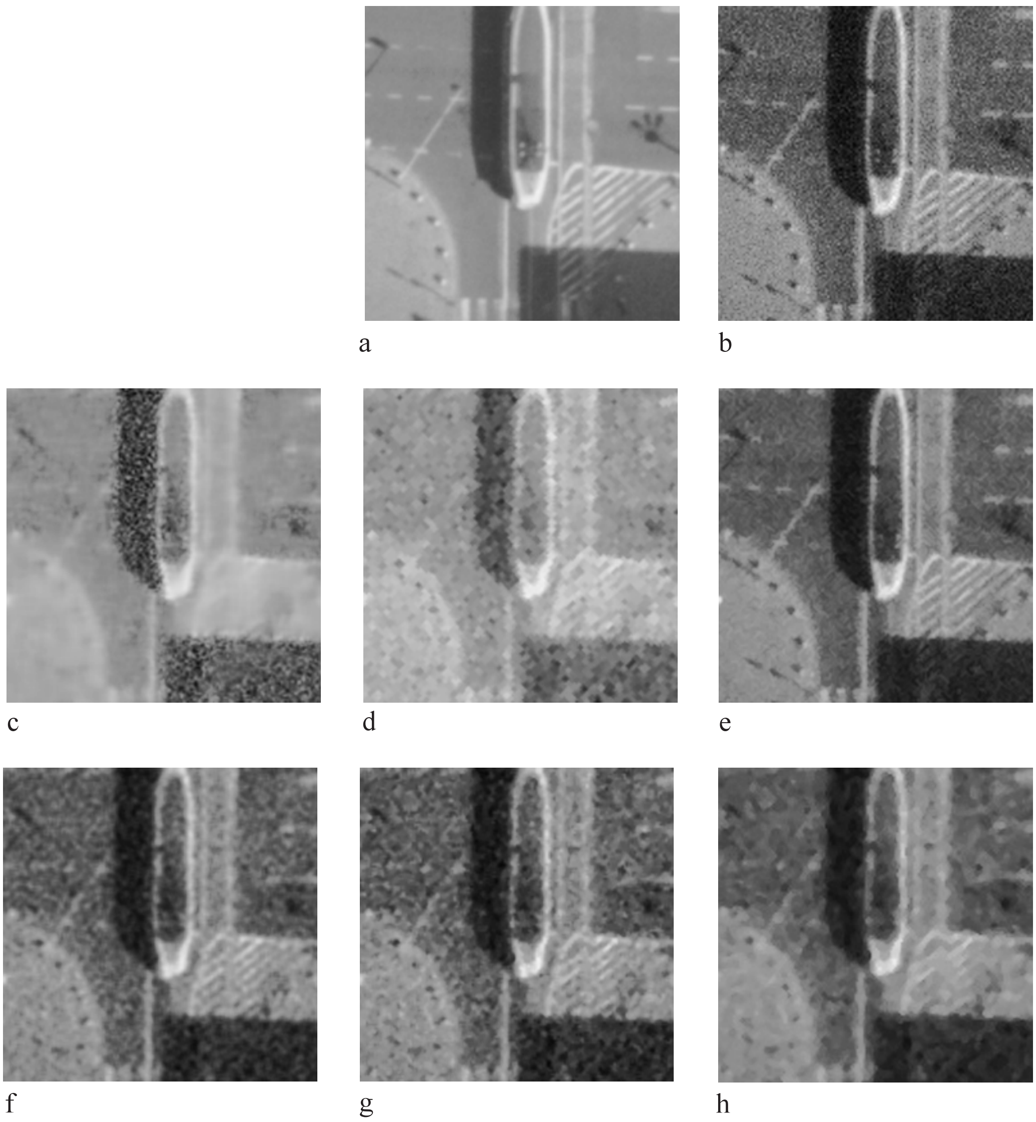

Figure 1. The part of aerial image: a – original, b – with the Gaussian noise,
after filtering: c – Frost Filter 7x7, d – Alternate Filter 3x3,
e – Alternate Filters with Multiple Structuring Function 3x3, f – Mean Filter 3x3, g – Median Filter 3x3,
h – Median Sequential Filter applied twice 3x3

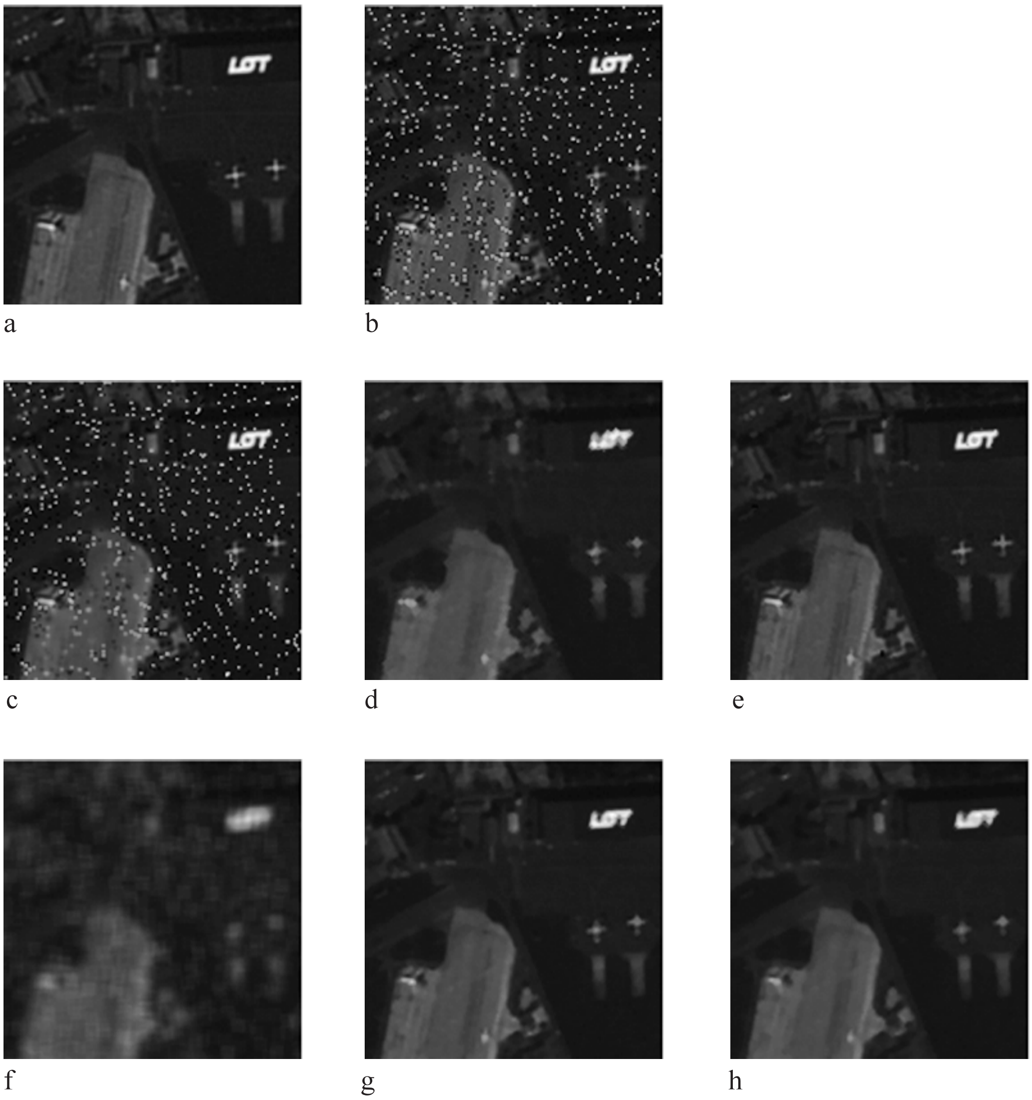

Figure 2. The part of satelite image: a – original, b – with the ‚salt and pepper‚ noise, after filering: c – Frost Filter 11x11, d – Alternate Filter 3x3, e – Alternate Filters with Multiple Structuring Function 3x3, f – Mean Filter 7x7, Median Filter 3x3, h – Median Sequential Filter applied twice 3x3