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Two-Pass Median Filter for Impulse Noise Removal

1. Introduction

Median filtration is one of the most popular methods of noise removal. It is especially useful in case of enhancement of images corrupted by impulse.

Applied to grayscale images, median filtration is a neighborhood brightness-ranking algorithm. Each pixel is equal to the median intensity of its closest neighborhoods in the original image. The size of the neighborhood is determined by the mask, which passes through the image row-by-row (or column-by-column) [1–7].

Median filtration has a long history and many references in the literature. It is described in almost every handbook on image processing [1–7]. Moreover, it is commonly used in many practical applications of vision systems as a part of image enhancement process. It is much more robust in impulse noise removal than the traditional linear filtering, because it preserves the sharp edges.

Regardless its popularity, there are some drawbacks to median filtration [8]. First of all it compromises details and blurry an image. Therefore, many modifications of classical median filtration have been developed. They involve different techniques, which allow to determine noise-corrupted pixels and decrease the number of pixels being filtered. In consequence they suppress impulse noise while preserving image details.

Numerous approaches for improving median filter efficiency have been defined so far. The following should be mentioned as examples:

- vector median filters [9–11];
- weighted median filters [12–21];
- matrix-valued median filters [22–23];
- multi-state median filters [24–26];
- switching median filters [27–31].

The approaches are often applied adaptively, in order to increase quality of median filtration [30, 32–37]. Recently, fuzzy techniques and neural networks [37–45] have also become popular in determining which pixels should be subjected to median filtration.

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In this paper the modification of median filter is presented. The proposed method filters only pixels corrupted by noise. In consequence loss of sharpness and important image information is avoided.

2. Noise preliminaries

2.1. Noise estimation method

Each noisy digital image has two main components: a stable signal and noise in accordance with equation [45, 46]:

$$L(x,y) = S(x,y) + N(x,y) \tag{1}$$

where:

- L – noisy image;
- S – signal component;
- N – noise component;
- x, y – pixel coordinates.

The image of noise can be simply determined from Equation (1) and described as follows:

$$N(x,y) = L(x,y) - S(x,y) \tag{2}$$

Image of noise should be possible to obtain by subtracting signal-only image from the noisy one. However, it is not possible to obtain signal-only image, but it can be approximated by the noise-reduced image. It means that estimation of noise can be achieved by subtracting approximation of signal-only image from the noisy one in accordance with Equation (3).

$$\tilde{N}(x,y) = L(x,y) - \tilde{S}(x,y) \tag{3}$$

where:

- $\tilde{N}$ – approximation of noise;
- $\tilde{S}$ – approximation of signal-only image.

Equation (3) is the most important one from the point of view of noise removal technique presented in this paper.

2.2. Impulse noise

Several types of noise have been defined [1]. In this paper the impulse noise is considered. This type of noise is characterized by probability density function $p(z)$ given by Equation (4) [1].

$$p(z)=\begin{cases}P_a & for \quad z=a\\ P_b & for \quad z=b\\ 0 & otherwise\end{cases} \tag{4}$$

where P_i – probability of *i-th* gray-level appearance.

If $b > a$ intensity b will appear as a light dot in the image. Conversely, level a will appear like a dark dot. If either P_a or P_b is zero the impulse noise is called unipolar noise. If neither probability is zero and especially if they are equal, impulse noise is called bipolar noise or more commonly salt-and-pepper noise. In case of 8-bit monochromatic images $a = 0$ (pepper) and $b = 255$(salt) [1].

3. Signal-to-noise ratio

In order to quantify noise level signal-to-noise ratio (SNR) is used. The higher SNR value the better quality of the image. Signal-to-noise ratio can be defined as follows [47]:

$$SNR(L,L')=10\log_{10}\frac{\sigma^2(L)}{MSE(L,L')} \quad [\text{dB}] \tag{5}$$

where:

σ^2 – image variance;
MSE – mean square error defined by Equation (6).

$$MSE(L,L')=\frac{1}{K}\sum_K d^2\left(L(x,y),L'(x,y)\right) \tag{6}$$

Symbols in Equation (6) denote:

K – number of pixels in the image;
d – the distance between signal-only image and noisy image.

In the following part of this paper signal-to-noise ratio is used to quantify and compare results of different noise removal algorithms.

4. Algorithm Description

The main stages of the proposed algorithm to impulse noise removal are:

1) approximation of the signal-only image;
2) noise map construction;
3) correction of pixels corrupted by noise (indicated by the map build in the step 2).

During the correction process median filtration is applied twice.

Firstly median filtration is applied to approximate the signal-only image. Filtered image is then subtracted from the noisy one, in order to extract the differences between those two images (see Eq. (7)). Because noise presence can both increase and decrease pixel intensity, the absolute value of the differences is used (in order to avoid negative values, which can not be displayed).

$$\tilde{N}(x,y) = abs(L(x,y) - \tilde{S}(x,y)) \tag{7}$$

where $\tilde{S}$ – median filtered (approximation of signal-only) image.

Information contained in image given by Equation (7) arises not only from noise presence, but edges unsharpness as well. However, the biggest intensity differences are assigned to pixels corrupted by noise. Noise information can be then extracted applying operation given by Equation (8).

$$M(x,y) = \begin{cases} 1 \quad for \quad \tilde{N}(x,y) \geq \partial_N + \bar{N} \\ 0 \quad for \quad \tilde{N}(x,y) < \partial_N + \bar{N} \end{cases} \tag{8}$$

where:

- M – noise map;
- ∂_N – standard deviation of image $\tilde{N}$;
- $\bar{N}$ – average gray level of image $\tilde{N}$.

In consequence map $M(x, y)$ of noisy pixels is obtained. It indicates pixels, which should be corrected in the last step of the algorithm. The correction is simple substitution of the intensity of the noisy pixel, with median intensity of its closest neighbors.

In case of applications of median filter mask sized 3×3 is used. Size of the mask was chosen experimentally (bigger masks increase algorithm computational complexity without significant influence on noise removal effectiveness).

5. Results

Results of successive steps of the algorithm applied to baboon image corrupted by an impulse noise are shown in Figure 1.

Figure 1a presents original (signal only) image. In Figure 1b noisy image can be seen. Result of noise removal using introduced method can be seen in Figure 1d. Moreover, map of noise is shown (Fig. 1c). SNR is indicated on each figure.

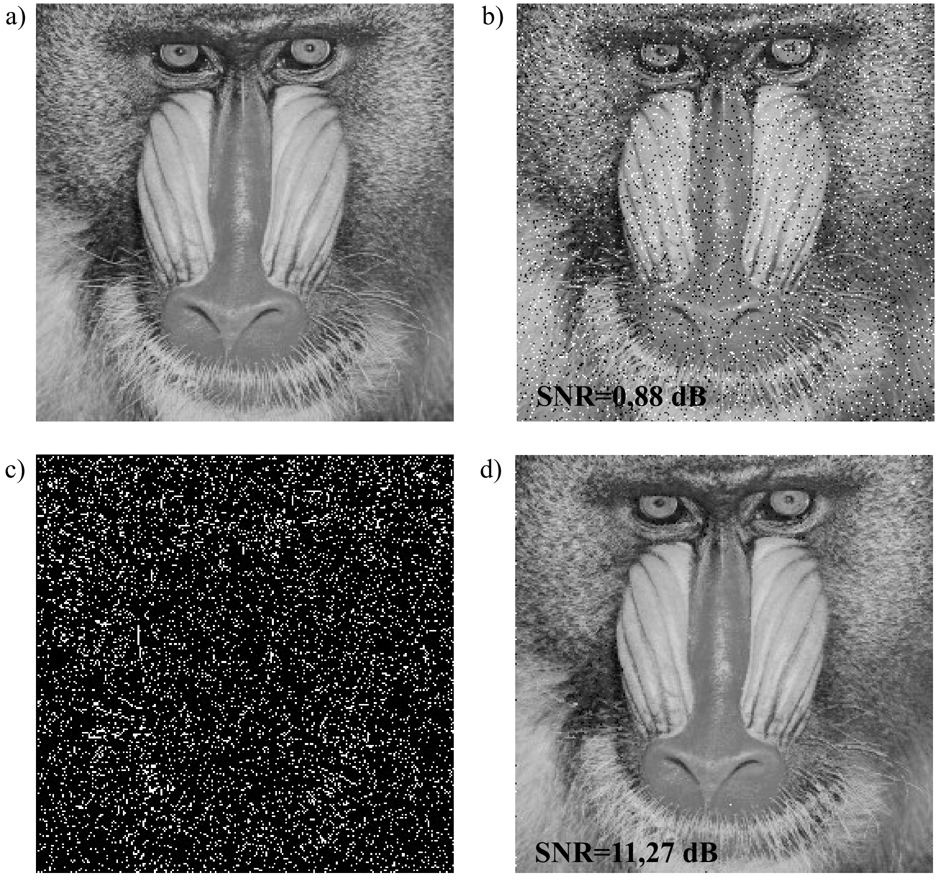


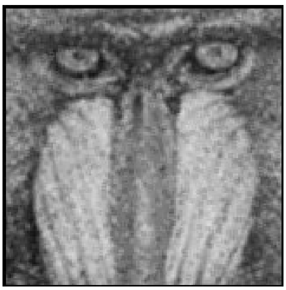
Fig. 1. Successive steps of the algorithm applied to baboon image:
a) original image; b) noisy image; c) map of noise; d) reconstructed image.
SNR values are indicated on images

6. Comparison with traditional approaches

Table 1 presents results of noise correction by different algorithms. The method used for noise removal is indicated above each image. The proposed method, median filtration, simple averaging and Gaussian filtration are considered [1, 2]. For median filtration and averaging mask sized 3×3 was used. The comparison of algorithms results is made by means of signal-to-noise ratio. SNR value is indicated under each image. Magnified part of baboon image from Figure 1b was used as a noisy image.

It can be easily seen that the new approach to impulse noise removal significantly improves signal-to-noise ratio. Obtained results are much better than in case of all tested traditional approaches. Introduced method results with over twice higher signal-to-noise ratio than in case of simple averaging and than in case of Gaussian filter. Also median filtration results with significantly lower signal-to-noise ratio, than the presented method. Moreover, all tested traditional methods of noise removal compromise details. Their application makes reconstructed image looks blurry and unsharp. Part of important information contained in the image is lost due to reconstruction process.

Table 1
Noise removal algorithms comparison

ORIGINAL IMAGE	NOISY IMAGE	MEDIAN FILTRATION
		
	SNR = 1,24 dB	SNR = 6,69 dB
AVERAGING	GAUSSIAN FILTRATION	AUTHORS' METHOD
		
SNR = 6,00 dB	SNR = 6,10 dB	**SNR = 11,62 dB**

In case of the presented method sharpness of the reconstructed image is far better. Furthermore more details are visible. Important image information is successfully restored. Reconstructed image precisely matches the original one. The differences between signal-only image and image after noise removal using the proposed algorithm are almost not distinguishable.

More results proving the new algorithm efficiency are presented in Figure 2 and Figure 3. Noise corrupted images of Goldhill (Fig. 2) and Zelda (Fig. 3) are used as examples.

Results of noise removal using traditional median filtration and the new approach are compared. The comparison is made by means of SNR. Its value is indicated on each image. Because of low efficiency of impulse noise removal results of Gaussian filtration and averaging are not presented.

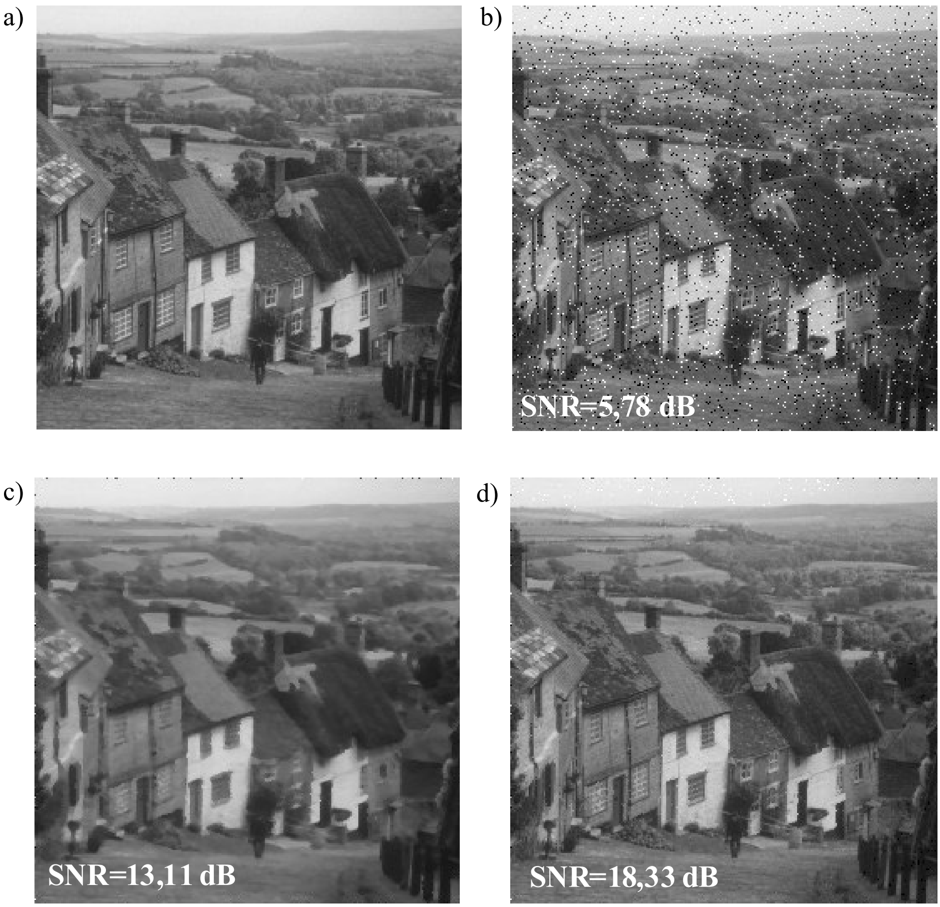


Fig. 2. Restoration of noise-corrupted Goldhill image:
a) original image; b) noisy image; c) median filtration; d) the new approach

Results presented in Figure 2 and Figure 3 confirm that the new approach to noise removal works more efficiently than the traditional one. Better quality of image reconstruction using introduced method is supported by higher signal-to-noise ratio. Moreover reconstructed images are sharper than in case of traditional median filtration. In consequence more details are preserved.

a) b) c) d)

Fig. 3. Restoration of noise-corrupted Zelda image:
a) original image; b) noisy image; c) median filtration; d) the new approach

7. Algorithm performance analysis

The quality of impulse noise removal using the proposed method depends on the level of input image degradation. Curves from Figures 4 and 5 present changes of SNR in reconstructed images in a function of percent of noisy pixels in the input image for Goldhill and Zelda respectively. The new approach and the traditional median filtration are considered. Negative SNR values mean that the noise component is higher than the signal component.

In Table 2 magnified parts of Goldhill image corresponding with the graph from Figure 4 are shown. First column presents part of the noisy image. Moreover in this column percent of noisy pixels and SNR are indicated. In the second and the third column result of noise removal using median filtration and the new approach respectively are presented. In both cases SNR values are indicated.

Because of high level of similarity to results presented in Table 2, results of noise removal from Zelda image corresponding with graph from Figure 5 are not presented.

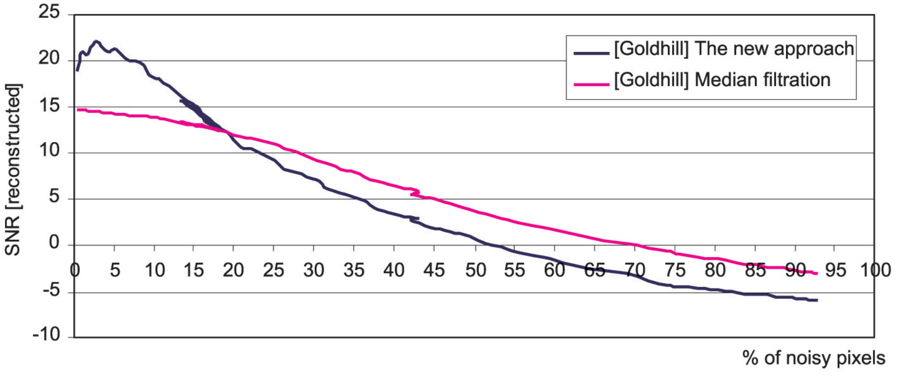


Fig. 4. The influence of percent of pixels corrupted by impulse noise on image quality restoration for Goldhill image

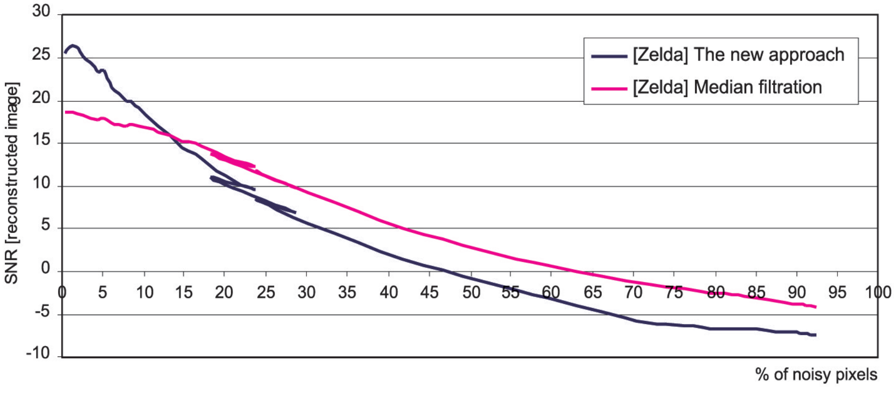
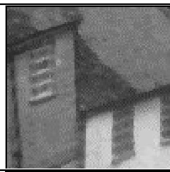
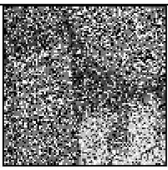
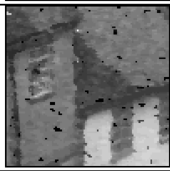
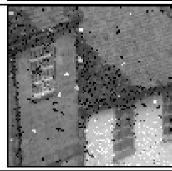
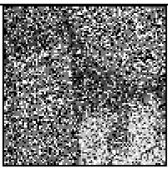
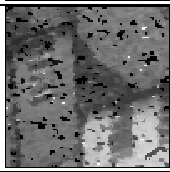
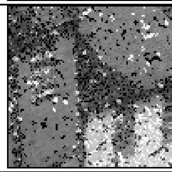
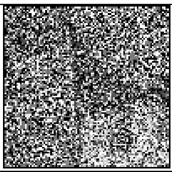
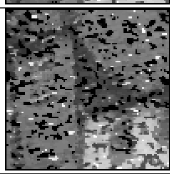
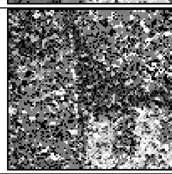
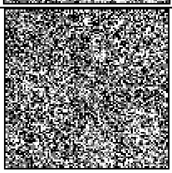
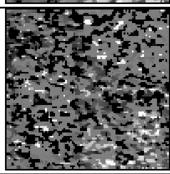


Fig. 5. The influence of percent of pixels corrupted by impulse noise on image quality restoration for Zelda image

Curves presented in Figures 4 and 5 show clearly that the new approach removes impulse noise more efficiently than the standard median filtration in case of images corrupted by noise in not more than about 15–20%. Better efficiency of noise removal is then confirmed not only by higher SNR value but subjective impressions (sharper appearance) as well (see Tab. 2). In case of images where more than 20% of pixels are corrupted by impulse noise traditional median filtration seems to be more efficient. However, it should be underlined that subjective valuation of results is still favorable to the new approach. Despite of lower SNR value after reconstruction more details are preserved.

Table 2
The influence of percent of noisy pixels on image restoration quality

Noisy Image		Median Filtration		The New Approach	
	1% SNR 13,58 dB		SNR 14,56 dB		SNR 20,99 dB
	10% SNR 2,97 dB		SNR 13,73 dB		SNR 18,20 dB
	20% SNR –0,12 dB		SNR 11,72 dB		SNR 10,62 dB
	30% SNR –1,72 dB		SNR 9,24 dB		SNR 7,06 dB
	50% SNR –3,75 dB		SNR 3,88 dB		SNR 0,99 dB
	70% SNR –5,17 dB		SNR 0,18 dB		SNR -3,04 dB
	90% SNR –6,47 dB		SNR –2,64 dB		SNR –5,62 dB

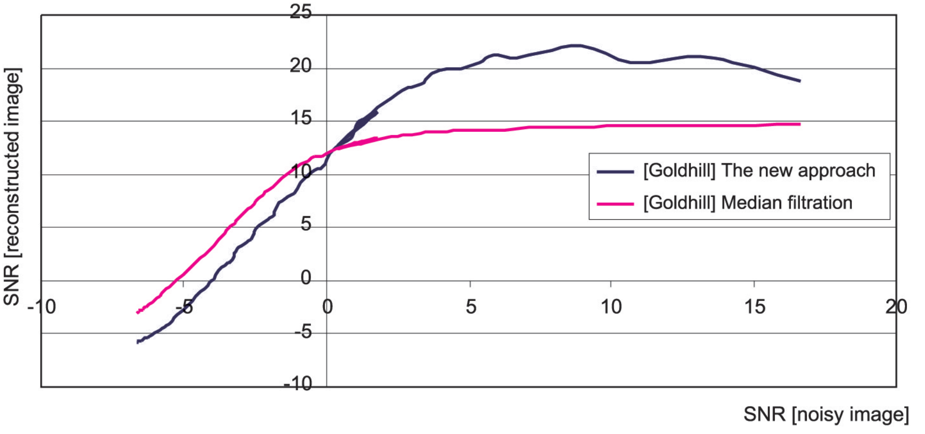


Fig. 6. SNR in restored image in function of SNR in the noisy one for Goldhill image

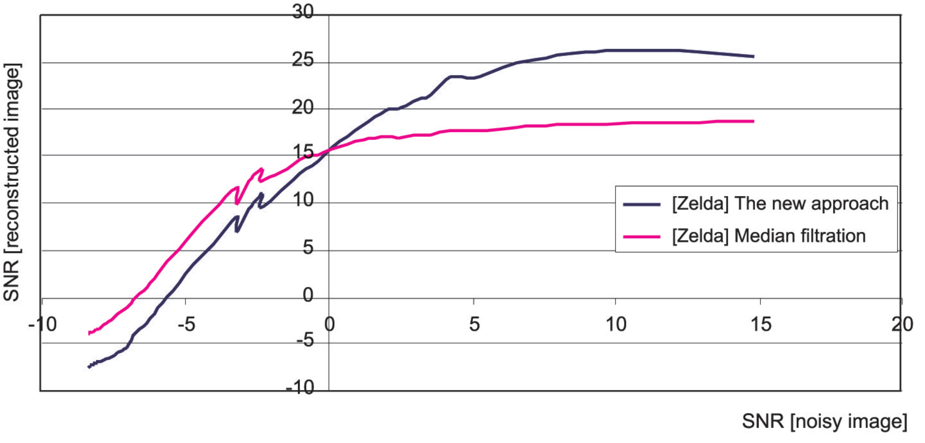


Fig. 7. SNR in restored image in function of SNR in the noisy one for Zelda image

In Figure 6 and Figure 7 curves presenting dependence of SNR in restored image on SNR in the noisy one are shown. Analogously to the previous ones, the curves were build based on images of Goldhill and Zelda respectively. The new approach and traditional median filtration are considered.

Analysis of curves from Figure 6 and Figure 7 leads to the conclusion that in case of images where signal component is stronger than the noise one (positive SNR values) introduced algorithm is more efficient than the traditional median filtration. It is confirmed by higher signal-to-noise ratio.

In case of images corrupted by noise in more then 50% or images where noise component is predominant its really difficult to decide which method is more efficient. Neither

SNR nor subjective impressions are sufficient. In such cases reconstructed image is practically useless from the point of view of most practical applications as objects placed in the scene are not distinguishable.

8. Conclusions

In this paper problem of noise removal from digital images was discussed. Particular attention was paid to the impulse noise. Custom methods of random noise removal were mentioned.

The new approach to impulse noise removal was introduced. Proposed method is two-pass median filter which reconstructs the original image from the noisy one. Results of the proposed method were presented and compared with those obtained by traditional approaches to noise removal. Simple averaging, median filtration and Gaussian filtration were considered. Moreover performance of the new approach was tested. Especially influence of the percentage of noisy pixels on image quality reconstruction was investigated.

Analysis of obtained results leads to the conclusion that effects of the proposed algorithm are much better than those obtained using traditional approaches. Reconstructed image precisely matches the original one.

Proposed method can be particularly useful in case of noisy images presenting different details. However, it can be also successfully used in all digital image processing and analysis applications as a part of image enhancement process.

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