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# Remarks on Noise Removal in Infrared Images

**Abstract**

Noise removal in IR (Infra Red) images is very popular in recent years, however the same approach is utilized as for vision images, with no or minor changes. In this work we wanted to show the results of noise removal for selected filters. We focused on investigation of some filters normally used for image processing and their influence to IR image quality. In IR imaging the choice of filter depends mainly on the purpose of the processing, e.g. detection of small objects in complex images, edge and contour detection or removal of non-uniformity of the detector array. The performance of the selected noise reduction filters was evaluated using PSNR (Peak Signal-to-Noise Ratio) and MAE (Mean Absolute Error) quality measure, greater value of the PSNR and lower value of the MAE indicate better noise reduction. The results are shown only for few images from our database which contain over 2000 of IR images.

**Keywords**: thermography, infrared images, noise removal.

## 1. Introduction

IR imaging is used nowadays in many fields of life and new applications are still developed. The examples of application of IR imaging are military, industry - including automotive and medicine. One of the most useful industrial applications of IR imaging is NDT (Non Destructive Testing) of materials [1] and one of the most recent is automotive night vision system based on human detection and tracking. Another example of the use of IR images is medicine, e.g. the measurement of the human body temperature [2]. The importance of IR images applications makes the quality of these IR images very important.

In literature, many authors claims [3, 4, 5, 6], that the foremost factor which influences the quality of IR images is presence of noise. It is common for IR images that the signal-to-noise ratio and the contrast are low. These two make the processing of IR images difficult, but the presence of noise is not so evident. The sources of noise are IR sensors and the interference of the signal processing circuit. Depending on the IR sensor technology it may be the problem connected with photoelectric conversion (in photodetectors) or temperature fluctuation noise (in thermal detectors) as well as the influence of manufacturing process [7]. The aforementioned problems cause IR detector non-uniformity, what is revealed by varied response of the pixels. This non-uniformity if not properly corrected, may be the main source of noise in IR images. Also the environmental conditions during the measurement should be considered.

Noise removal in IR images is very popular in recent years, however the same approach is utilized as for vision images, with no or minor changes. In IR image processing the best approach is to use the temperature data immersed in JPEG image file instead of image only. But on-line processing is difficult, cause temperature data is available for user only in dedicated software, supplied with thermal imager. This is real problem, when commercially available thermal imagers are utilized. Custom hardware solution based on raw IR detectors, e.g. FPA detectors does not suffer from this problem. Also image processing is more efficient than large raw data (temperature) manipulation.

Through the years a lot of methods of noise removal have been examined. Some of them were adopted from traditional image processing, like for example the median filter; some others were converted to improve their influence on IR images, like the center-weighted median filter and methods related to fuzzy logic [3].

The classical methods of noise removal, for example the median filter, can be used in the case of IR images, but the results can be blurred. The reason is the fact that this type of filters have been dedicated to visual image processing, where the signal-to-noise ratio is much more bigger than the one for IR images. After using the median filter the important details and small elements can be lost. If the object of interest is very small, it can happen that the critical information can be incomprehensible. The reason of this situation is the fact that the median filter has influence on every pixel of the image both the disturbed and the undisturbed. Some of the solutions propose using the median filter combined with other methods to reduce noise and improve filtering results. Examples of these other methods can be: statistical test, edge detection kernel or Boolean filter [8–10].

Currently, the applications of wavelet transform for noise removal in IR images is popular. Noise removal is based on thresholding of wavelet coefficient at certain level of signal decomposition on its low and high frequency components. An overview of this method in application for IR images for different noise types is presented in [11].

During the last years, noise removal methods connected with fuzzy logic have been developed. Examples of this type of methods can be found in [12, 13]. These methods provided good results. The idea of using fuzzy logic is justified by the fact that whereas in classical Boolean algebra, the variables can only take a value true or false, in the case of fuzzy logic every variable can take a value between 0 (totally false) or 1 (totally true). The membership function will decide about these values, the function need to be previously defined. This solution can result much more efficient than the median or Gaussian filter.

Recent articles on noise reduction in thermal images strongly points out the influence of impulse noise (salt & pepper) on the image quality [3, 6, 14]. In our opinion it is not common in raw thermal images, especially captured by the LWIR (Long Wave InfraRed) cameras with FPA (Focal Plane Array) uncooled microbolometers. This type of noise can be a result of further image processing or transmission. It is also not common in vision images, but readily used by the authors for filter performance testing. However we should ask the question, is it really right way, because this type of noise is marginal. Also authors in their publications overlook the information about the particular IR camera or detector type utilized in their investigations. This information can be very important and helpful. The noise in IR images is not only determined by the detector but also by background and emissivity fluctuations of the object. This is clearly shown in [15, 16] for small object tracking. The real problem we met in raw thermal images is the specific disturbance which occurs in many images, appearing as vertical lines. This occurs particularly, but not only in low contrast images - with object temperature close to the background temperature. The examples of poor and good contrast thermal images for the same object is presented in figure 1. Background temperature for both was about 20°C. The noise in infrared images is not only determined by the detector but also by background and emissivity fluctuations of the object.

## 2. Noise source in IR images

Most popular and cost effective IR cameras are the LWIR equipped with FPA uncooled microbolometers. The infrared systems based on cameras of that type have noise of about 80 mK, while the objects of interest (the targets) are typically several Kelvin hotter than their background. In most cases, especially indoor, e.g. room, laboratory, it is achieved and acquired images are with low apparent noise. Outdoor, the IR images acquisition is influenced by environmental conditions and the object temperature can be drastically reduced by atmospheric loss. Especially at long distance, through dust, smoke, or fog. Unfortunately some targets are near the temperature of their background. Targets may also be situated such that the background seen in the image is not located close to the target, such as an object on top of a hill. These conditions can greatly reduce the signal to noise ratio of an image.

Fig. 1. Poor contrast (left) and good contrast (right) IR images. Left: mug of water, temp. about 22°C, right: mug of water, temp. about 35°C

The important problem is thermal stabilization of the IR camera. As mentioned earlier, the main source of error in IR images is non-uniformity of FPA and read-out circuits of IR cameras. The time required to stabilize the thermal properties of IR camera can differ according to the camera manufacturer. In most of the cases the non-uniformity of FPA is reduced already in the cameras software, but still the output image can be affected by the noise, especially when the objects temperature is similar to the environment. Thermal images we used in this work have been captured with a Wuhan-Guide TP8 IR camera. The camera is equipped with a 384×288 pixel uncooled FPA microbolometer, spectral range is 8 – 14 μm and thermal sensitivity 0.08 °C. The time required for stable response of the camera is more than 75 minutes [2].

## 3. Noise removal

A number of noise reduction methods have been proposed. As was mentioned in Introduction many of them were adapted to IR images ground. In conjunction with a number of possible noise sources in IR images, it is difficult to answer the question, what kind of noise is dominant in a particular image. The choice of filter depends mainly on the purpose of the processing, e.g. detection of small objects in complex images, edge and contour detection or removal of non-uniformity of the detector array. The use, in noise simulation, the Salt & Pepper noise is also disputable. In most cases, if impulsive noise occurs, the pixel in image is affected with the same probability in full color or grayscale range, not only 0 or 255 like in salt and pepper.

For this work we choose four representative noise reduction filters in our opinion, i.e. median, fuzzy, density estimation and wavelet transform filters. In Figure 2 four typical examples are shown. First, the sky with five pigeons and pieces of roof has been presented. The pigeons should be treated as small objects in the thermal image. In the second image the street with buildings, cars, people has been showed.

Median filter reduce the noise from images based on an assumption that signal pixels have high correspondence with their neighbor pixels inside a small area, known as filtering window. Using neighbor information will cause the loss of some thin lines and textures. Small targets and objects often occupy only a few pixels in the IR image, also are surrounded by the pixels with high gradient, thus during filtering process many of them can be replaced by the median pixel and consequently removed from the IR image. In [6] the authors introduced modified median filter for application to IR images. The assumption is: if the gray-level $g(x,y)$, where $x$, $y$ are coordinates of the central pixel in filter window, is equal to the maximum gray-level *gmax* or the minimum gray-level *gmin* inside a filter window, the pixel is noisy and should be replaced. This works fine for salt and pepper noise, but not for color noise which is more common in images. A comparison of noise reduction in image disturbed with Salt & Pepper and color noise with this filter is presented in Figure 3. The ordinary median filter works well with both types of noise, while proposed in [14] only for salt and pepper, where is more effective than ordinary one.

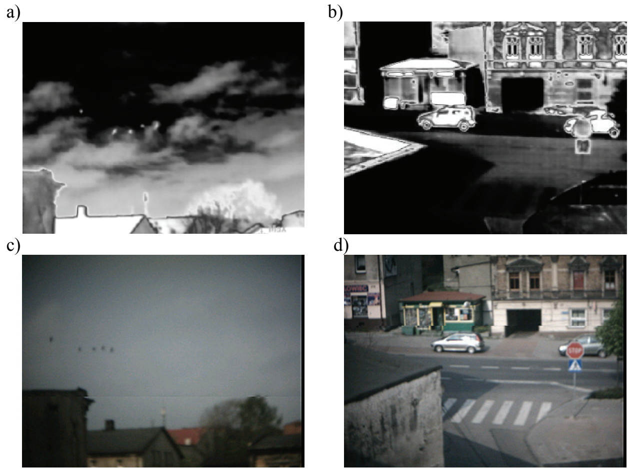



Fig. 2. Sample IR images (top) and visual images (bottom) with different type of image details

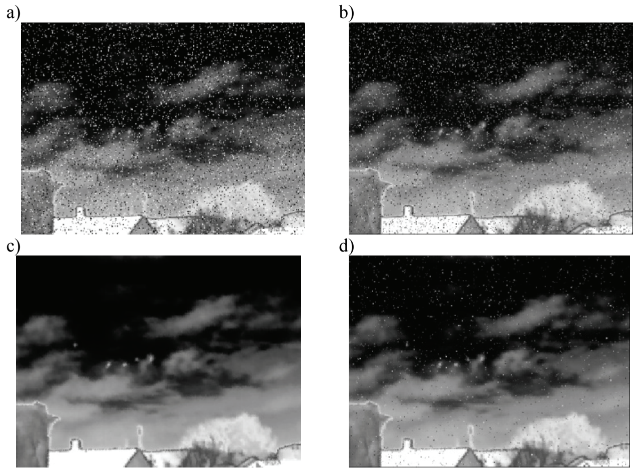



Fig. 3. Results of noise removal in image disturbed with salt and pepper noise (a) and color noise (b). c) PSNR for filter proposed in [11] is 33.3 (for ordinary median filter PSNR = 30.7); d) noise not removed from image disturbed with color noise , PSNR = 24.8 (for ordinary median filter PSNR = 32.3)

Statistical pattern recognition is another reliable technique for noise reduction. It requires the estimation of the probability density function of the data samples [17]. Nonparametric density estimation is based on placing a kernel function on every sample value and on the summation of the values of all kernel function values at each point in the sample space [18]. At the start the selected/center pixel in the window is removed. Next, for all of the pixels in the filtering window the density estimate should be calculated and then the pixel with maximum value of this function replace the selected pixel, in most cases center pixel in the window. Using the Gaussian kernel function, the density estimate of the unknown probability density function at $x$ is obtained as a sum of kernel functions placed at each sample $xi$ [19].

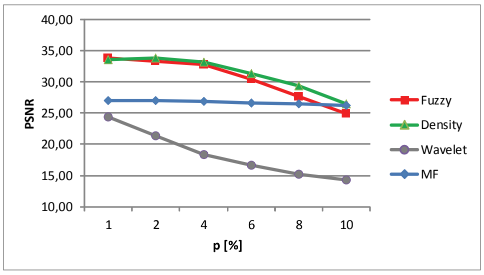
$$p_N(x,h) = \frac{1}{N(h\sqrt{2\pi})^m} \sum_{i=1}^{N} \exp\left(-\frac{\|x-x_i\|^2}{2h^2}\right), \quad (1)$$

where: $h$ is the smoothing parameter, $m$ = 1, $N$ is a number of pixels in the filtering window, $x$ is a selected pixel in the filtering window, $x_i$ is the next pixel in the window.

Another possibility is to reduce noise using fuzzy filters [20]. Generally, it processes human knowledge in the absolute values to fuzzy range. In fuzzy filters the similarity degree is calculated with its neighbours to know the similarity level between them. Next, these absolute values are converted to fuzzy values using similarity level, i.e. small and large degree of similarity. This similarity level is also known as the membership function, which can be created using only human knowledge about e.g. noise filtering procedure, influence on the final result of the texture in the image etc.

Wavelets are very popular tool for image denoising, because additive noise can be removed while preserving important features of the image. In wavelet denoising the most important is proper thresholding of the coefficients. The idea of thresholding was shown by Donoho and Johnstone [21, 22]. In discrete wavelet analysis image is decomposed into the low and high-frequency components respectively. High frequency components includes noise which is reduced through thresholding algorithm. The decomposition is done at a few levels using a specific low-pass and high-pass filters. Many publications on wavelets describe this procedure, so we will not describe it here in details. The important is, that after decomposition and wavelet coefficient thresholding, the image is reconstructed with definitely lower level of noise. In this work, we used the Haar wavelet, 4-levels of decomposition, minimax thresholding rule and hard thresholding.

a)




b)

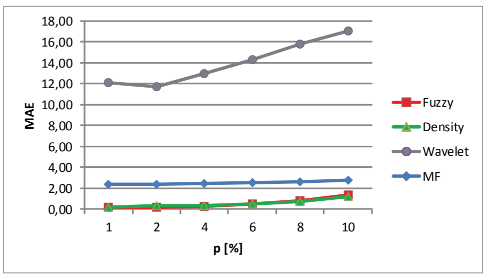



Fig. 4. Results of PSNR and MAE calculation for IR image shown at Fig. 3

The performance of the selected noise reduction filters have been evaluated using PSNR and MAE quality measure. The selected IR images shows most commonly situations during IR images acquiring. First, the impulsive noise reduction filters have been evaluated. The impulse noise probability ranges from $p$ = 0.01 to $p$ = 0.1. In Figure 4 the PSNR and MAE results are shown. Best results we get for Density Estimation filter, especially at lowest noise probability, which is very close to real IR image. Wavelet transform produces poor results, due to poor removal of impulsive noise, but preserves edges of the objects (see Fig.8). Especially effectiveness of filtering can be evaluated using MAE – smaller value of the MAE corresponds to better quality image. In this case based on MAE values Wavelet filter produce very poor results, the results of the three others filters are satisfactory.

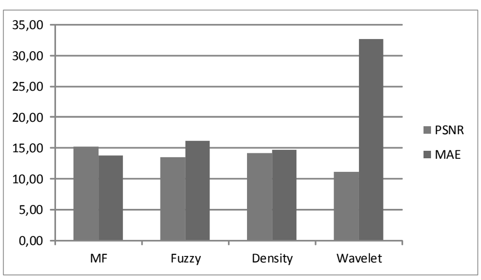



Fig. 5. Results of PSNR and MAE calculation for IR image shown at Fig.2b noised with $p$=0.2

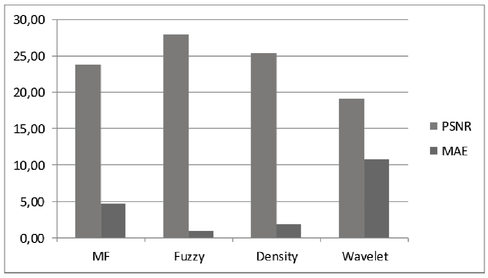



Fig. 6. Results of PSNR and MAE calculation for IR image shown at Fig.8 (left) noised with $p$=0.04

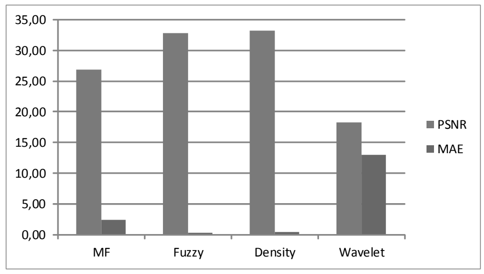



Fig. 7. Results of PSNR and MAE calculation for IR image shown at Fig.8 (right) noised with $p$=0.04

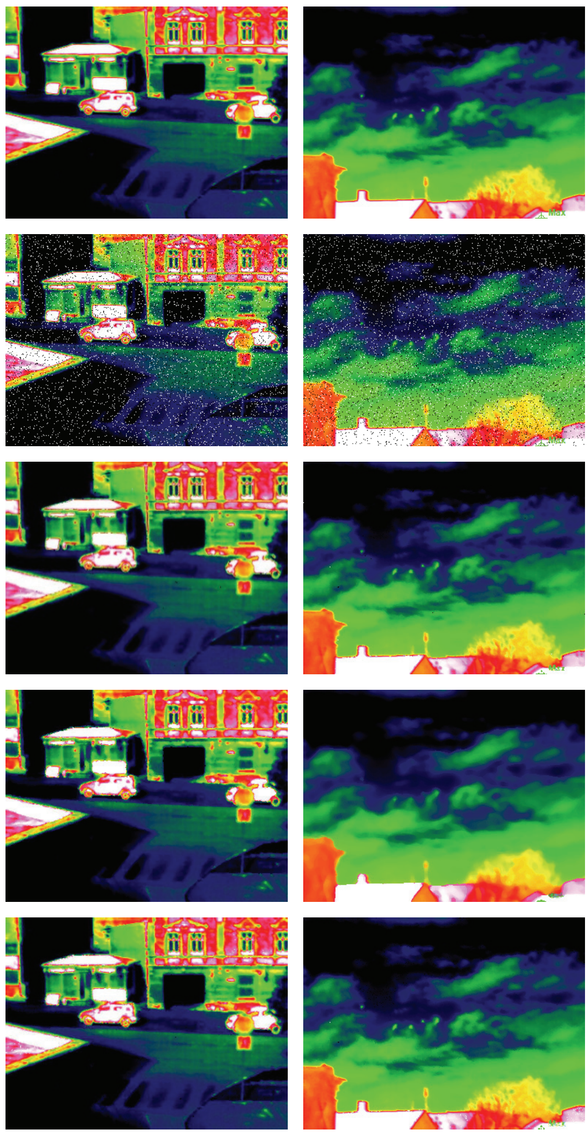


Fig. 8. Results of IR images denoising for noise density $p$=0.04, original image, noised, fuzzy filtered, MF filtered, density filtered (top-bottom order)

Figure 5 shows significant results. The tested image was noised with $p$=0.2, evaluated results obtained using all of the examined filters produce poor results – wavelet worst. This situation shows, how the IR images vary from visual images and why in most of the cases noise reduction filters produce poor results. First, the noise at the higher level, e.g. $p$=0.2 does not correspond to the real situations – especially if we take into considerations only Salt & Pepper noise. Typical IR images are smooth, including homogenous regions with the same temperature. Filters, which take a neighbours information are very sensitive for any of the pixel that have different value in relation to neighbours. In regions, where we have dynamic changes in the temperature the filtering results are quite good, even for higher value of the noise.

In Figure 6 and 7 the PSNR and MAE quality measure for images presented in Figure 8 has been performed. In Figure 8 five processed IR images have been presented for two different examined images. Left images corresponds to the street IR image with many details in the texture, but also with some regions with the same temperature. All of the used filters decrease overall quality of the image, of course they remove the added noise with different level, but the edges of the objects such as car, buildings are corrupted. In consequence, further processing e.g. detection and recognition of the specific objects, can be difficult. Better result we obtain after filtering IR i In literature, many authors claims mage shown at the right of the Fig.6. This IR image contains group of pigeons (small objects in the image center) and large regions with similar temperature. Fuzzy and Density Estimation filters produces similar results and preserves small objects in the image. Small objects e.g. each pigeon, in the IR images can be treated as noise pixels.

## 4. Conclusions

In this paper the problem of noise removal in IR images has been presented. We showed that noise in IR images, described in literature, is exaggerated and denoising can degrade small object of interest. Other hand, the small objects that occupy maximum several pixels can be processed as the noise. Thus, choice of the noise reducing filter is important task. Results show, that the taken filters, excluding MF filter can be used as classical noise reduction filters, even we processed thermal images, not visual one. The nature of the noise should be investigated, because it's quite different in thermal images regarding to the visual one.

Results presented in Fig.4 and Fig.5 show poor properties of the filters, as results of the assumption, that the IR images are corrupted by impulsive noise in large amount. In most practical situations it is hard to get quite noised thermal images, thus classical noise reducing filters can be used effectively for thermal images denoising and small objects detection process (see Fig. 8).

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