A NEW APPROACH TO EDGE-PRESERVING SMOOTHING FOR EDGE EXTRACTION AND IMAGE SEGMENTATION

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ABSTRACT

This paper introduces a new approach to edge-preserving smoothing of digital images. It is designed for an effective elimination of the image noise within digital images what is an essential step in applications like edge detection or image segmentation.

The approach presented here tries to overcome some of the disadvantages of existing smoothing filters and is conceived as an extension of the edge-preserving Maximum Homogeneity Neighbour Filter. The algorithm cleans up the image noise in the homogeneous areas, but preserves all image structures like edges or corners. It is shown that the new filter algorithm combines the advantageous features of different types of filters. The algorithm is not only applicable to grayscale images, but can be extended to multi-channel data, like color images too.

The performance of the algorithm is achieved by a more complex and differentiating treatment of the image data compared to conventional concepts.

KURZFASSUNG

Es wird ein neuer Ansatz zur kantenbewahrenden Glättung von Digitalbildern vorgestellt. Wenn Merkmale wie z.B. Kanten aus einem Digitalbild extrahiert werden sollen oder eine Bildsegmentierung durchgeführt werden soll, muss zuerst ein Filterprozess angewendet werden, um das Bild vom Rauschen zu säubern.

Der hier vorgestellte Ansatz versucht, einige der Nachteile der bestehenden Glättungsfilter zu überwinden, indem der Maximale Homogene Nachbar Filter erweitert wird. Der Algorithmus beseitigt das Bildrauschen in den homogenen Bereichen, während alle Bildstrukturen wie Kanten oder Ecken bewahrt bleiben. Es wird gezeigt, dass der neue Filteralgorithmus die erwünschten Eigenschaften verschiedener Filtertypen vereinigt. Der Algorithmus kann nicht nur auf Grauwertbilder angewendet werden, sondern auch auf Mehrkanaldaten wie z.B. Farbbilder.

Die Leistungsfähigkeit des Algorithmus basiert auf einer komplexeren und differenzierten Behandlung der Bilddaten als bei bisherigen Konzepten.

1 INTRODUCTION

1.1 Motivation

This paper introduces a new approach to edge-preserving smoothing of digital images as a preprocessing step for feature extraction and/or image segmentation. Although there are many filtering algorithms available, the results of these algorithms are not satisfying for all applications. In specific cases of object detection, as to be performed in an ongoing research project, standard algorithms may have deficiencies. Here, the detection process has to work even under bad conditions, making it necessary to have a reliable algorithm. The objects to be detected within the digital images are sometimes very small (eg. down to 3*3 pixels), the contrast is sometimes low and considerable radiometric noise has to be allowed.

1.2   The smoothing problem

In every digital image there is a certain amount of white noise. If feature extraction algorithms like interest point operators or line extractors are applied or if an image segmentation will be done, many of the features to be found, like small edge elements, for example, are only expressing the existing image noise. To avoid these annoying effects, which only consume computation time and affect the real image features, firstly a filtering process has to be applied to the original digital image, in order to get rid of the image noise.

Then the problem arises, that the smoothing of the image within the homogeneous areas has to be achieved without blurring those gray value changes which are containing the information needed. Especially for following feature extraction steps it is essential to preserve the edges and corners, with respect to their geometrical shape and magnitude of the gradient.

2   EXISTING SMOOTHING ALGORITHMS

2.1   Lowpass filters

The most commonly used smoothing algorithms are the n*n-boxfilter and the Gaussian Kernel Smoothing (Binomial Filter). Here, a square-sized convolution kernel is applied to each pixel. With the parameter "boxsize" (n) respectively "sigma", the degree of smoothing can be controlled.

This smoothing strategy results in very nicely smoothed homogeneous areas, however possessing the disadvantage to blur gray value edges. This leads to three problems:

- The edge region will be extended due to averaging of edge and non edge pixel. So the edge may come closer to other edges with the effect that they are no longer detectable as separate edges.
- Corners are rounded off and small crinkles are blurred. This means that image structures are geometrically damaged, what might be fatal for the following feature extraction.
- The magnitude of the gradients is degraded. In the worst case, the edge cannot be detected at all, because the magnitude falls beyond some given threshold.

2.2   Edge-preserving algorithms

Edge-preserving smoothing filters are much more suitable for feature extraction. Some examples of this filter class are:
- Median Filter
- Symmetrical Nearest Neighbour Filter (SNN)
- Maximum Homogeneity Neighbour Filter (MHN)
- Conditional Averaging Filter

These non linear algorithms are calculating the filtered gray value in dependence of the content of a defined neighbourhood. From the list of the neighbourhood pixels, only these are taken for the averaging, which have similar gray values compared to the pixel in consideration. Each edge-preserving filter has its own specific algorithm, but they all have in common, that the effect of this smoothing strategy is to preserve edges. Unfortunately, these smoothing filters have the characteristic not to smooth satisfyingly, because small gray value fluctuations existing in the really homogeneous areas are emphasized and not reduced. In addition, the Symmetrical Nearest Neighbour Filter is unable to produce reliable results in case of small areas.

3   DEVELOPMENT OF THE NEW APPROACH

3.1   Requirements for an algorithm with superior results

In order to overcome the problems mentioned above an extended algorithmic concept has been designed which has the following features:
- high degree of smoothing in the homogeneous areas
- preserving of edges, even those ones being represented by small gray value changes
- conservation of very small homogeneous image regions.

The algorithmic extension is based on the edge-preserving Maximum Homogeneity Neighbour Filter, because it meets the last two demands. The concept of this filter is enhanced, taking the strategy of segmentation techniques like region growing into consideration, providing a higher degree of smoothing in the homogeneous areas.

3.2 The Maximum Homogeneity Neighbour Filters (MHN)

Maximum Homogeneity Neighbour Filters are checking the homogeneity of small areas (the size is often 3*3 pixels) within the close neighbourhood of the pixel in consideration. Different implementations use a different number of areas (Kuwahara et al.: 4 areas, Tomita et al.: 5 areas, Nagao et al.: 9 areas, Wang: 9 different areas) which are composed differently (Wang, 1994). They all have in common, that all pixels within the area are connected and that the pixel to be edited belongs to all areas. The choices of Wang, for example, are shown in figure 1.

As criterion for the detection of the area with maximal homogeneity may serve the variance of the gray values within the area, or the minimum rank order difference.

The new value for the pixel in consideration is then calculated either from the mean or the median value of the region of maximal homogeneity.
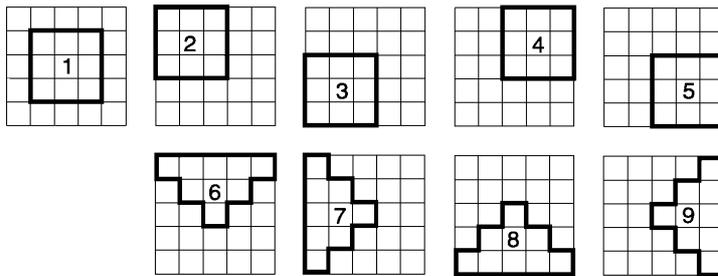
Figure 1. Definition of the masks of the 9 small areas (Wang, 1994)

3.3 The segmentation idea

Algorithms for image segmentation take the radiometric properties of the pixels into consideration. While split-and-merge algorithms compare two image regions, region growing algorithms execute a test, whether a single pixel radiometrically fits to an existing region. Fitting means, that the value must lie within the interval given by the average gray value of the region plus and minus n-times (e.g. n=3.0) the standard deviation of gray values of the region. This means to have a variable threshold automatically determined in dependence of the gray value statistics. As the magnitude of the white noise is mostly unknown and furthermore signal dependent, this does simplify the application of such an algorithm.

3.4 The new algorithm

The MHN filter is lacking a high statistical significance, because of the fact, that only a few (e.g. 9) pixel are considered for the test of homogeneity. Such few pixel are rarely able to represent the statistical behaviour of larger regions. In our approach, the result of the MHN filter is only used as an indicator for a further statistical analysis of a larger neighbourhood. Every pixel within a given radius or rectangular box is tested onto its radiometric similarity to the area of highest homogeneity having been extracted by the MHN filter. The size of the larger test area is of minor importance and may amount up to 10 pixel in square. Finally, the gray value of the pixel currently being processed is calculated as the average of all pixels meeting the criterion. This processing has the advantage to consider a larger number of pixels for the filtering step resulting in a considerable improvement of the homogeneity of the image areas.

The parameterisation for the algorithm is robust. The only two thresholds having to be adjusted are the boxsize for the statistical analysis of the neighbourhood pixels and the standard deviation factor, which can be put to 3.0 without scruple. This simplifies the use of the algorithm compared to the Gaussian Kernel Smoothing, for example, where the adjustment of the sigma threshold often turns out to be very critical.

3.5 Upgrading of the algorithm to multi-channel images

Up to now, only gray values have been considered. However, in the ongoing project colour images will be used too, making it necessary to have the algorithmic conception transformed into the colour space. It is obvious, that an upgrading of the gray value formulas into multi-channel formulas is quite simple.

First, the criterion for the detection of the area of maximal homogeneity has to be replaced. It is of convenience to check the variances within the different channels separately and then to select that area, where the maximum of the standard deviations of all channels is minimal. Second, the judgement of the radiometrical correspondence of pixels from the larger neighbourhood has to be extended to all channels. This will be done by combining the results for each channel. If for this aggregation a logical addition of the investigations in all individual channels is used, one furthermore gets the advantage to increase the stability of the results.

4 RESULTS

4.1 Preserving of image structures

The new algorithm preserves the geometric shape of all image structures as well as the original MHN Filter does. Figure 2 compares the effect of some smoothing filters on a gray value edge with a low signal/noise-ratio. The effect of the Gaussian Kernel Filter is a blurring of the edge, while the two other algorithms preserve the edge significantly.
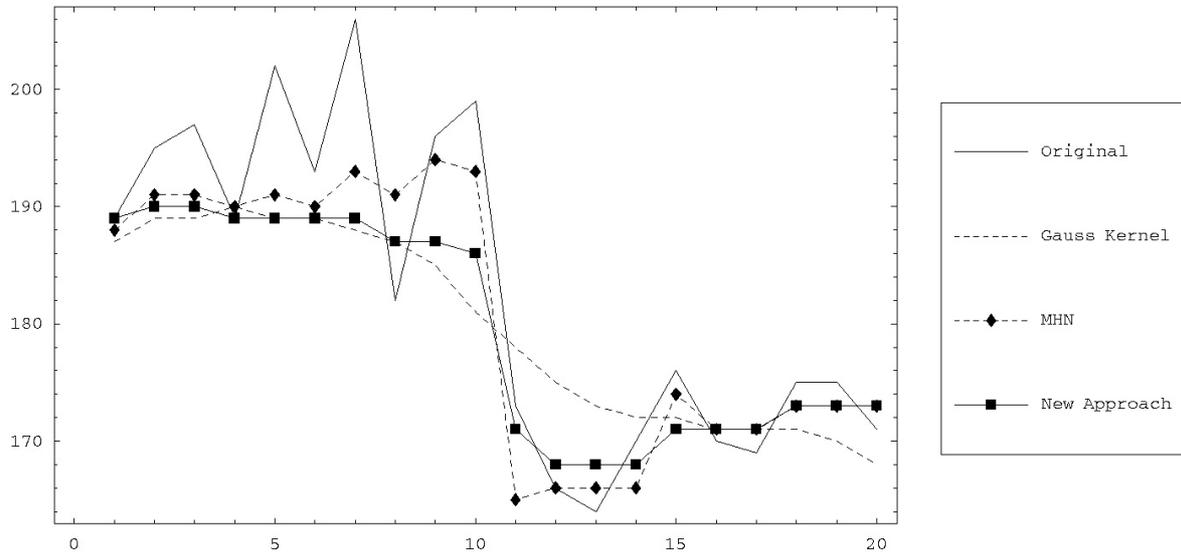

Figure 2. Effect of smoothing filters on a gray value edge

The conserving effect for important image structures is to be found in Figure 3 too. Here images are displayed after different smoothing filters having been applied. It is obvious, that the geometric shape of all images structures is preserved in the cases (c) and (d). Comparing with the result of the Gaussian Kernel Smoothing (b) a blurring of the edges and an off rounding of the corners is avoided.
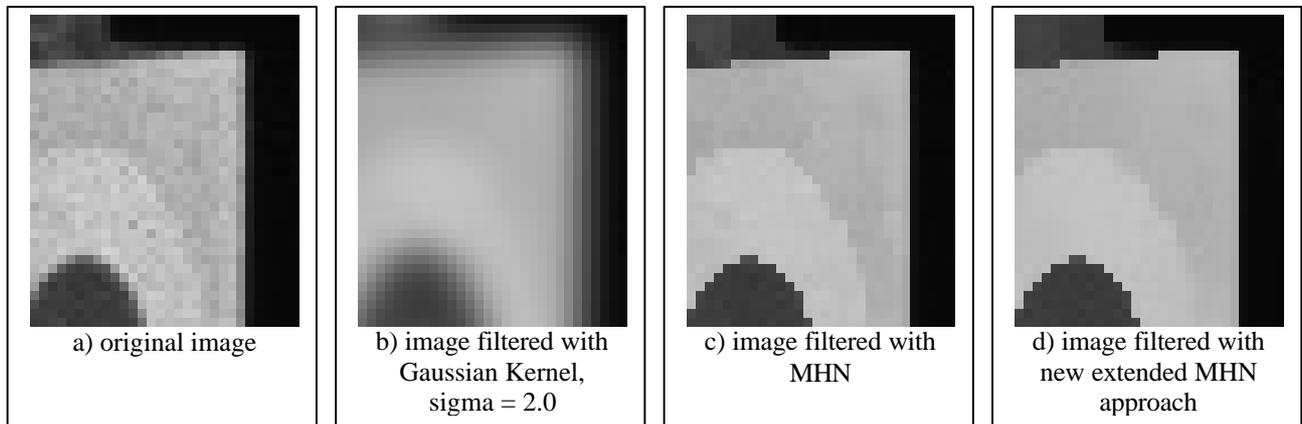

| a) original image | b) image filtered with Gaussian Kernel, sigma = 2.0 | c) image filtered with MHN | d) image filtered with new extended MHN approach |

Figure 3. Resulting images after different smoothing filters applied

4.2 Noise cleaning

With respect to noise cleaning, the degree of smoothing of the new algorithm is considerably higher than for conventional edge-preserving algorithms. For Gaussian Kernel Smoothing, the degree of smoothing depends on the adjustment of the sigma threshold. Figure 4 shows a comparison of the calculated gradient magnitude that remains after the different filters have been applied. Obviously, the Gaussian Kernel smoothing (b) produces a high degree of smoothing, but the strength of the gradients representing the real edges has been degraded. The edge-preserving filters (c) and (d) conserve the edge gradients. It can be seen, that the new strategy (d) leaves a significantly smaller amount of spurious gradients in the homogeneous areas than the conventional MHN (c).
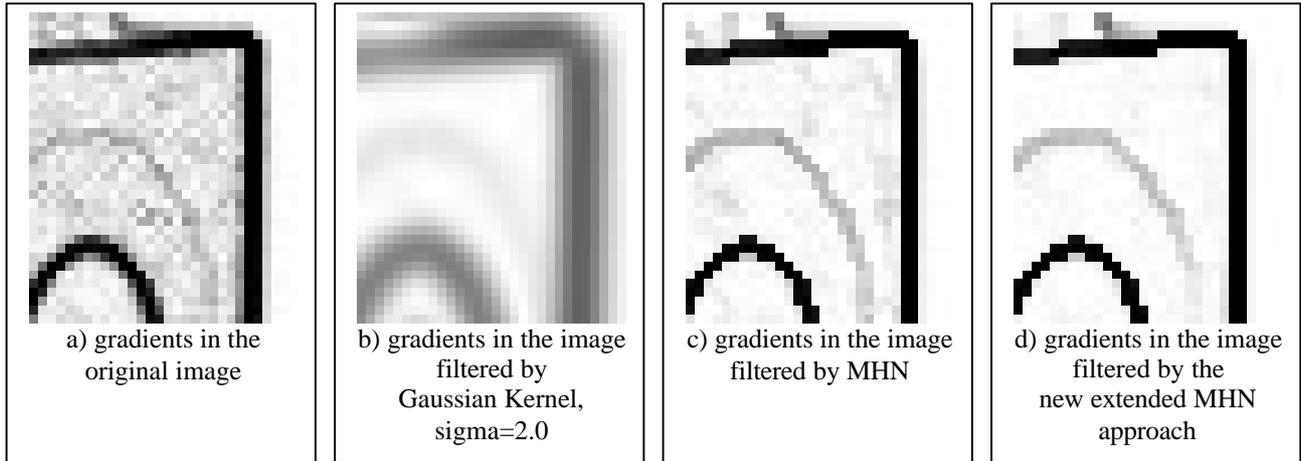
Figure 4. Gradient magnitudes in the filtered images

A more quantitative assessment of the capability to reduce noise effects is expressed by numerical values as shown in table 5. Here, a comparison of the standard deviation of the gray values in homogeneous areas is given, after the different filters have been applied. 36 homogeneous areas of the size 7*7 pixels were selected by visual inspection, differentiated by the amount of noise in the original images. It can be seen, that all algorithms perform well as long as the amount of noise is low. In the cases of high noise, the new approach performs just as good as the Gaussian Kernel smoothing with sigma=2.0, but much better than the conventional MHN algorithm.

Image / Filter applied		original image	Gauss Kernel, sigma = 0.5	Gauss Kernel, sigma = 2.0	MHN	new approach
standard deviation of gray value	low noise	0.80	0.64	0.37	0.53	0.45
	medium noise	3.42	2.50	1.10	1.67	1.12
	high noise	6.11	4.31	1.33	2.67	1.26

Table 5. Standard deviation in homogeneous areas

4.3 Effects on the following feature extraction

Of further interest is the impact of the mentioned pre-processing steps onto following edge extraction processes. As an example Figure 6 shows the image overlaid with the results of such an edge extraction. The new smoothing algorithm (d) produces an output image that is almost noise-free, but that still contains all existing significant image structures. It is now possible to apply feature extraction algorithms like interest point operators, line extractors or to perform an image segmentation producing results not being affected by effects of noise. Since the edges are geometrically and radiometrically preserved, the results of an edge extraction algorithm are of superior quality. In contrast to the Gaussian Kernel Filter (b) the corners are not rounded off, and edges that lie closely together remain separately detectable. In
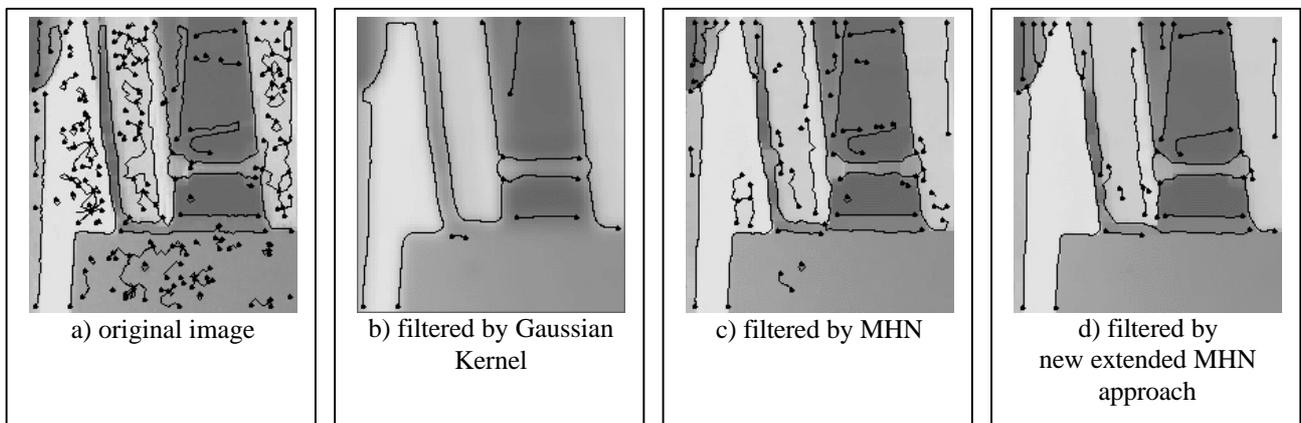

Figure 6. Image overlaid with the results of Canny edge extraction

contrast to the conventional edge-preserving filters the amount of disturbances like small edge fragments due to noise in the homogeneous areas is considerable smaller.

The application of the algorithm also simplifies the parameterisation in the following feature extraction steps. This is achieved because the magnitude of the edges is preserved, and the magnitude of the gradients in the homogeneous areas is put almost down to zero, what facilitates the adjustment of thresholds. In case of the use of the Canny edge detection algorithm, for example, the gradient magnitude threshold can be set to somewhat like 5 gradient units. This threshold does no longer depend on the strength of the noise in the original image.

4.4 Computation time

Due to the complexity of the calculations, the new algorithm needs more computation time than conventional ones (cf. table 7). In the presented example a region of size 9*9 pixel has been used for the extended approach. The cost for this extension, which has been used in the example of table 5 too, is about 60% compared to the base computation time for the MHN approach.

Filter	Gaussian Kernel	SNN	MHN	new approach
time (s)	10	15	17	27
	test image: 512 x 512 , 3 channels , Computer: 233 MHz AMD			

Table 7. Comparison of computation times

5 CONCLUSION

Often it is not crucial what filtering algorithm is chosen for image smoothing, but if the results are supposed to be of superior quality, and if the quality of the input data is problematic, intense attention has to be paid to concept, structure and impact of the pre-processing algorithm to be applied.

It has been shown that the algorithm newly developed brings together the desired features of different types of filters. It is a combination of the Maximum Homogeneity Neighbour Filter and segmentation techniques. The algorithm provides a high degree of smoothing in the homogeneous areas, but preserves all image structures like edges or corners. So the following feature extraction steps can be applied without the effects of noise.

Possible fields of usage of the proposed approach are in principle all applications where image improvement is necessary, especially as a pre-processing step for feature extraction or image segmentation. The scale of the images is irrelevant, so the algorithm can be applied to aerial images as well as to all kinds of close range images. The number of channels is irrelevant, too.

If the image only contains a very low amount of noise, or if the objects having to be detected are comparatively large or if the local image contrast is great, the results are just as good as those performed by conventional algorithms.

Because the algorithm needs more computation time than conventional ones, it will primarily be worth the effort, if the feature extraction promises to be tricky. This may occur if some of the homogeneous areas that have to be extracted are very small (eg. down to 3*3 Pixels) or if the contrast between adjacent areas in the images is low (eg. less than 10 gray value units). If the images contain a high amount of noise, the usage must be recommended, because the results are significantly of superior quality.

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