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SPECKLE REDUCTION BY AN ADAPTED GEOMETRIC FILTER PRINCIPLE

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ABSTRACT

In this paper a novel and efficient approach of despeckling is presented based on the principle of geometric filtering. This approach works independent from a specific speckle distribution, involving simply the typical speckle appearance. Based on the powerful method of an adaptive and rapid stepwise convergence of each data point suitable to the estimated convex hull from its neighbours, many fields of application with similar conditions are conceivable. These include e.g. a fixed pattern noise reduction in infrared imaging or a speckle pattern elimination in SAR images additionally to the in this paper chosen filtering of speckle disturbed ultrasound images. The medical images processed by the proposed filter method are speckle reduced and fine grained images with preserved texture.

***Index Terms*—** nonlinear filter algorithm, geometric concept, adaptive filter, despeckling, texture preservation

1. INTRODUCTION

The importance of sonographical examination rises during the last years. Ultrasound imaging is used in novel medical fields of application because of its real-time-capability and its noninvasive, nearly unharmful character compared to imaging procedures of diagnostic radiology. Some serious progress is achieved in the field of the image quality enhancement by conditioning the ultrasound-signal (e.g. THI, Focusing) for enhancing the contrast and resolution, etc. Nevertheless, an existing problem in this field of application is the appearance of the so called speckle noise pattern - a pattern caused by interference between scattered ultrasonic waves received from inhomogeneous scattering tissue. Although it is basically a deterministic process its appearance is more a specific random noise due to an unpredictable tissue structure. To support the visual interpretation and the quantitative measurement of body tissues during medical examination, real-time restoration of the ultrasound data is required. Many known approaches use an approximation of the speckle distribution as a basis for a mostly time consuming data restoration step [1].

Filters that require an a priori knowledge of the speckle distribution are MAP[1] Bayesian one-level filters like the Gamma MAP filter by Lopes et al [2].

MMSE[2] filters like the Lee filter [3], Kuan filter [4] or Frost filter [5] and their enhanced versions [6] [7] additionally includes speckle statistics in the filter process. Some further - time consuming - filter approaches with partial support of speckle statistics are anisotropic diffusion filters summarised in [8].

Other proposed filters for speckle reduction are the Oddy filter [9] and its extension - the HK filter [10]. These filters are algorithmic complex averaging filters - using a variable shape of the local window according to a local statistic for the suppression of speckle noise. Both filters belong to the group of the Sigma filters. Sigma filters take only pixels within the so called sigma environment around a central pixel for filtering into account.

2. THE GEOMETRIC FILTER CONCEPT

Crimmins proposed in [11] a geometric filter for speckle suppression. The structure of the geometric filter expects a simple geometric model of noise instead of a specific noise statistic. Its principle is based on the interpretation of several speckle spots as hills and valleys around the undisturbed signal. This valleys and hills should be stepwise filled and carried off respectively - under consideration of a target value defined by the convex hull. The filter process is therefore an iterative process where the value of the current central pixel b will be interrelated with its neighbourhood a and b (Fig.1) by a fixed policy. The comparison iterates stepwise from north-south, west-east, northernWest-southernEast, northernEast-southernWest.

Based on the original approach from Crimmins this paper presents a modified geometric filter principle with an adapted policy (Eq.1-2) and a varying step size s instead of a fixed one. A single iteration diminishes the difference of the speckle spots to its surrounding area by this s.

$$(a \geq b + s) \wedge (b + s \leq c) \Rightarrow b := b + s \quad (1)$$

$$(a \leq b - s) \wedge (b - s \geq c) \Rightarrow b := b - s \quad (2)$$

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[1] Maximum a posteriori

[2] Minimum mean square error

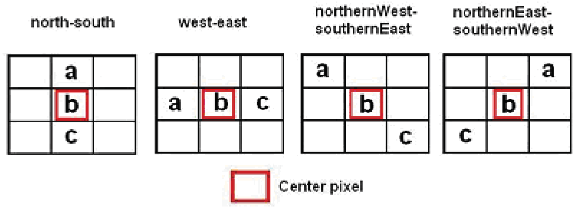


Fig. 1. Sequential neighbourhood for stepwise comparison of the geometric filtering.

For an entire elimination of the noise influence some more cycles with suitable step sizes are necessary. Because of the cyclic reduction of the hills and valleys it is useful to compensate still existing distortions with an appropriate reduced step size.

Thereby intense distinctive speckle spots requires adequate high step sizes. In combination with only a few iterations and an appropriate decreasing function $s(k, s_{start})$ for the step size some smaller discontinuities (e.g. texture of a homogeneity) can be preserved. Basically the chosen start step size s_{start} will be incrementally decreased with increasing cycle k.

There are tuned functionals $s(k, s_{start})$ of step size adaptation for the specific fields of application declared. Generally the best results for this sonographical image filtering application are derived by using the exponential decreasing function from Eq.3.

$$s(k, s_{start}) = exp = s_{start} \cdot \exp \frac{-k \cdot |\log s_{start}|}{k_{max} - 1} \quad (3)$$

Furthermore, the filter process can be controlled by the parameter k_{max} as threshold for the maximum number of iterations. Alternatively, the approach converges if the noise is too low concerning the step size parameter s. To ensure stability of this geometric filter implementation it is necessary to filter only in cases when the tendency of the required alteration of the signal value of the pixel under observation is remained also after its adaptation by the current step size (see Eq.1-2). That means a lower signal level has to be preserved and vice versa.

The simplicity of the model may lead to the elimination of all local hills or valleys regardless of their signal levels or exact causes - assuming an appropriate parametrisation is given. However, due to the simplicity there are further requirements. The distance between several speckle spots has to be larger than the window width. Furthermore, the speckle dimension should be as small as possible. Otherwise speckle would be preserved.

3. FURTHER ENHANCEMENTS

In this section further adaptations are presented. A greater amount of optional adjustability ensures a wide range of conceivable fields of application.

3.1. Step sizes / conditional filtering

In addition to a manually chosen global start step size the proposed geometric filter approach supplies some further methods for the choice of suitable step sizes to ensure best results by a given maximum of adjustability.

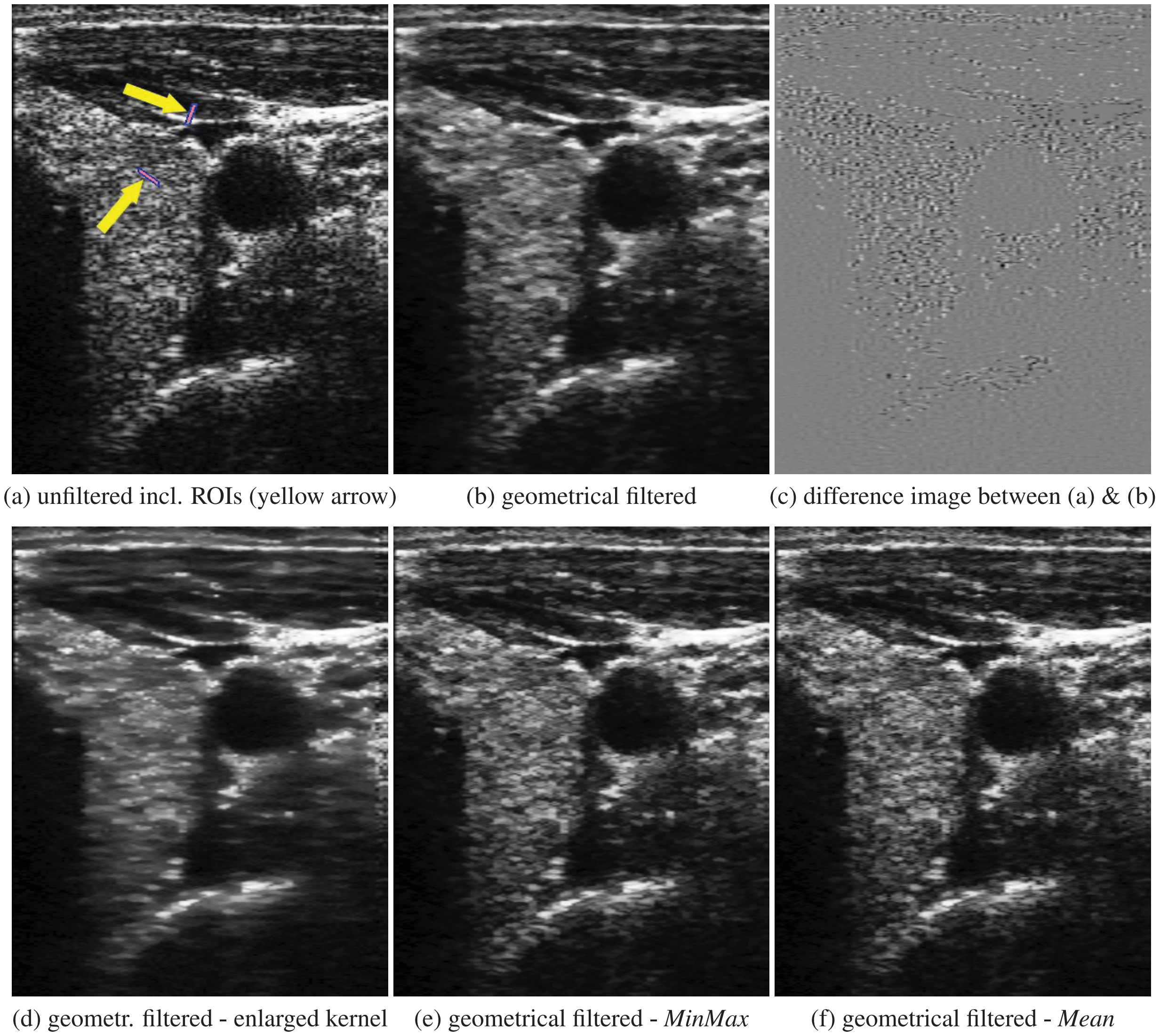
First, there is the possibility of using local start step sizes in the form of a feature map adapted to the amount of noise. Therefore the pixel values from the morphological filtered current image (e.g. median filtered) are scaled by a (e.g. linear) function to obtain suitable start step sizes. So this feature map includes start values s_{start} pixel by pixel - adapted on the current image - which will be used and processed (i.e. decreased - dependent on function $s(k, s_{start})$) during the filter process. The extracted feature map can also be interpreted as a pixel mask for the filter step. Only masked pixels (with current step values above zero) will be filtered. This procedure leads to a reduction of computing time due to the decrease of the amount of processed pixels. Because of the time reduction it is possible to filter the masked pixel by using more iterations to enhance the quality of the filter result.

Alternatively, the local step size can be determined of the *mean* of the gradient from the current pixel to its neighbourhood. This method exclusively avoids the observance of pixel value tendency after filtering and thus enables an overshooting of pixel tendency. That means a dark pixel can become brighter than some of its neighbouring pixels and vice versa.

A third and last kind of speckle suppression of the proposed filter uses the minimal or maximal value of the neighbouring pixels for replacing the speckle greyscale value. Considering the pixel tendency, dark speckle spots will be replaced by the minimum and vice versa. In the opposite to this *MinMax* ‘step size’ a *manually* chosen step size does not eliminate the valleys and hills completely. Its rather an approximation towards the *MinMax* result to preserve some more texture.

3.2. Neighbourhoods

The original geometric filter approach takes only a two pixel neighbourhood per comparing step into account. One iteration consists of comparing steps in four directions (Fig.1). It is not possible to make a general statement by using a - sequential - two pixel neighbourhood whether the current spot corresponds to speckle or to a thin line. This sequential scheme can be converted to a non-sequential 4- or 8-pixel neighbourhood. Although this does not conform with the principle of geometric filter its effect brings some advantages. Using a greater neighbourhood induces a more restrictive character of the filter step. The policy and the fact of keeping the pixel tendency diminishes the amount of regions where filtering is allowed. This procedure limits the applica-


(a) unfiltered incl. ROIs (yellow arrow) (b) geometrical filtered (c) difference image between (a) & (b)

(d) geometr. filtered - enlarged kernel (e) geometrical filtered - *MinMax* (f) geometrical filtered - *Mean*

Fig. 2. Sonographical cross-section of the human neck gathered with a linear probe.

tion of filtering to bright and dark speckle spots. The central pixel will be adapted only once instead of the sequentially adaption of the central pixel regarding to its changing neighbours.

To reduce the computing time it is possible to switch the neighbourhood in each cycle from the horizontal and vertical elements to the diagonal elements, and vice versa.

Different approaches of a chosen neighbourhood (4 or 8 neighbouring pixel, sequential or non-sequential) have a great influence to the fineness of grain. The following enumeration shows an increasingly smaller amount of affected pixels for filtering from top to bottom.

1. sequential 8 pixel
2. sequential 4 pixel cyclic switched
3. sequential 4 pixel
4. non-sequential 4 pixel cyclic switched
5. non-sequential 4 pixel
6. non-sequential 8 pixel

That means the neighbourhoods at the bottom preserves more texture and maybe (some) more speckle in less time.

3.3. Kernel width

Until now, the need for a lateral speckle dimension of value one was emphasised. Our proposed geometric filter overcomes this restriction by using a variable kernel width in x- and y-direction. For providing stability it is necessary to use - alternating with the enlarged kernel width - a kernel width of one together with an appropriate step size. It is conceivable to avoid the usage of a global kernel width and to use a local one for best adaption of the filter to the speckle appearance.

Table 1. geometric filter parameters for the several results from Fig.2

Parameters	Symbol	Fig.2(b)	Fig.2(d)	Fig.2(e)	Fig.2(f)
max. iterations	k_{max}	3	4	2	1
start step size	s_{start}	256	64	MinMax	Mean
decreasing function	$s(k, s_{start})$	exp	exp	-	-
neighbourhood	N_x	N_8	N_8	N_4 cyclic	N_8
sequential processing of N_x	$\sum N_x(.) \pm s(.,.)$	x	x	-	-
kernel width	κ [(x,y)]	(1,1)	(1,2)	(1,1)	(1,1)
iterations using enlarged κ	$iter_\kappa$	-	2	-	-
time*	t [ms]	10	13	6.7	4.4

* using Intel®Core^{TM}2 Duo CPU E8400 @ 3.00GHz, 4GB RAM

4. EXPERIMENTS AND DISCUSSION

In this section some speckle filtered results (Fig.2) - using the parameterisation given in Tab.1 - are presented. The basis for the geometric filter evaluation is a speckle cluttered ultrasound picture of the human neck (Fig.2a). In this image is an artery, a vein, a muscle and parts of the thyroid gland depicted. These structures are represented by thin lines like the inner and outer walls of the artery as well as the boundaries of the muscle and its muscle fibres. A homogeneous texture is given by the thyroid gland. All these characteristics have to be preserved during speckle reduction.

The images mentioned above are taken from the end of an ultrasound processing pipeline. The filter step takes place on the full 16 bit scale before the image is converted to 8 bit data and before a scan conversion is performed. This procedure ensures a filtering on the (lateral) undistorted speckle pattern and a reduction of the computation time. Otherwise the filter process - especially the adaptation of the step size - is corrupted by the greyscale value of the neighboured lateral expanded speckle spots or the expanded speckle spot itself.

To illustrate the local conditional filter characteristics in speckle disturbed regions, Fig.2c shows the difference between a geometrical filtered image (Fig.2b) and the unfiltered one (Fig.2a). While the fineness of grain appearing in Fig.2b,e,f is nearly the same, Fig.2d clarifies the stronger smoothing influence by an enlarged filter kernel width. Since the speckle pattern is eliminated within a few iterations and the edges and textures are preserved on the same time, there are no problems with the real-time capability of the filter.

The profiles from Fig.3 visualise the effect of the presented filter parameterisations from Tab.1 within a defined region of interest (Fig.2a). In the upper profile is a main edge depicted which is preserved very well by all filter versions. The profile below shows the influence of the filter approaches to a homogeneous region corrupted by bright and dark speckle spots. The *Mean* and *MinMax* filter kernel modifies the spots mostly in contrast to the geometrical filter with *manually* chosen step size and only a few iterations. It is also recognisable that the Mean filter kernel ignores the preservation of pixel tendency as the only approach. Based on this profiles it is not discernible why the speckle spots are eliminated like visualised. Therefore, it is important to consider the lateral greyscale value distribution to the pixels of the profile which can not be depicted in this 1d profiles but has a great impact on the filter result.

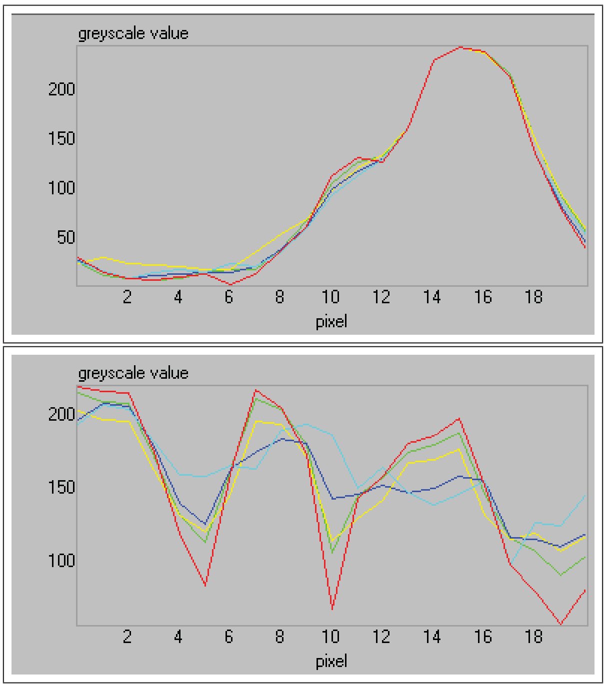
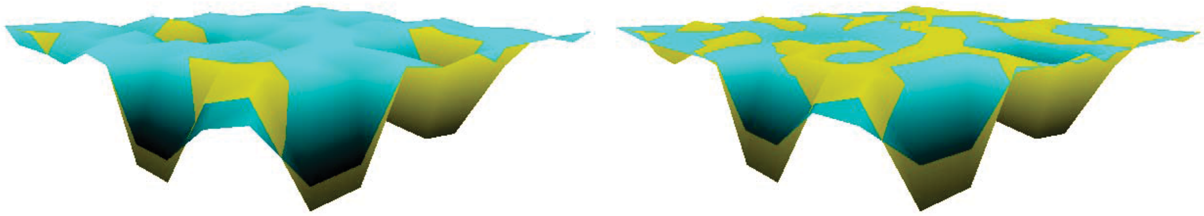


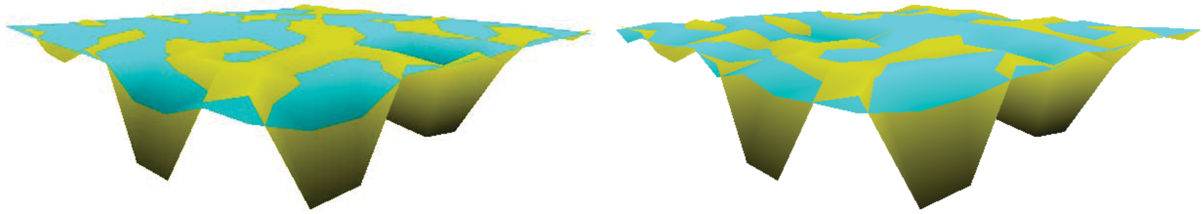
Fig. 3. 1d profiles of greyscale values over an amount of pixel (see ROIs in Fig.2a) representing an edge (above) and a homogeneity/texture (below).
[unfiltered pixel (red); geometrical filtered (green) - enlarged kernel (yellow) - *MinMax* (blue) - *Mean* (light blue)]

A better illustration of a speckle pattern suppression is given in Fig.4 by an exemplary elimination of some dark speckle spots. The horizontal plane corresponds to the image plane while the mountains represents the greyscale values of the unfiltered or the blended filtered image. For an improved visualisation of it-



(a) 1 iteration

(b) 5 iterations



(c) 10 iterations

(d) 1 iteration - *MinMax*

Fig. 4. Artificial unfiltered speckle disturbed homogeneity (yellow) and its filtered equivalent (light blue) after a given number of iterations in 3d representation.

erative speckle elimination a filter parametrisation[3] is selected which has to take some more iterations for this task into account.

As illustrated in Fig.4a, some less iterations preserves texture in combination with a high step size in relation to the texture but diminishes the appearance of the dark speckle spots. With every iteration these spots will be filled stepwise (Fig.4b,c). Some of the small valleys or hills are eliminated in Fig.4c by a steadily decreased step size induced over increasing iterations which allows to modify the pixel values with respect to the policy. To avoid this effect of influencing small structures, local adapted (Sec.3.1) or larger step sizes in combination with a more suitable decreasing function and adapted maximum number of iterations (Sec.2) or a more restrictive neighbourhood relation (Sec.3.2) should be used.

In contrast to the manually chosen step size, Fig.4d shows the exemplary filter result by using only one iteration with *MinMax* step size. The dark speckle spots were well replaced by the minimum of their neighbouring greyscale values. At the same time the texture is preserved similar to the results reached by applying the iteratively decreased step size in Fig.4a-c.

5. CONCLUSIONS

This paper presented a fast and robust method of speckle suppression based on the geometric filter. The optical assessment of the filtered images attests good results in speckle pattern elimination under consideration of a fine texture- and edge preservation. Furthermore, the quality of the filter results have to be evaluated regarding the requirements in the usually following image processing steps - like segmentation and classification.

A weighted overlaying of the filtered ultrasound image with the original unfiltered image can be advantageous if the speckle suppressed image seems rather artificial. Unless the image data is corrupted by further noise it is necessary to combine the proposed filter approach with other suitable filter methods. The combination of these different principles ensures to exploit the particular potential.

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