USE OF FRACTAL DIMENSION IN SIGNAL ADAPTIVE FILTERS FOR SPECKLE REDUCTION IN ULTRASOUND B-MODE IMAGES

X. Magnisalis C. Kotropoulos I. Pitas M.G. Strintzis

Department of Electrical Engineering, University of Thessaloniki, Thessaloniki 540 06, GREECE

Abstract

Two novel signal-adaptive nonlinear filters are proposed for speckle reduction in ultrasound B-mode images. The first is a modification of the Signal-Adaptive Median, which uses the Fractal Dimension (FD) as a measure of the local signal activity. The second one is based on the L_2 mean filter which is the maximum likelihood (ML) estimator of a constant signal corrupted by multiplicative Rayleigh noise and uses the above-mentioned measure of local signal activity. The proposed signal adaptive nonlinear filters suppress the speckle noise while preserving the image texture.

1 Introduction

In many object identification problems in Image Processing, the noise corruption includes additive as well as multiplicative and/or signal dependent components. In the ultrasound tissue characterization class of problems the general signal x-observation y relationship is as follows [1] :

$$y = x + x^a n_1 + n_2 \tag{1}$$

where the value of the parameter a, $0 < a \leq 1$, depends on the specific ultrasound sensor used and the preprocessing done, and n_1 , n_2 are independent noise proccsses. In such cases, the use of signal adaptive algorithms has been seen to be very helpful in general [1,2,3]. This paper developes two signal adaptive algorithms for speckle reduction and texture characterization in ultrasound B-mode images. The first relies on a median filtering formulation similar to that in [3] but with the Fractal Dimension (FD) rather than the Signal to Noise Ratio (SNR) used to effect the needed adaptation. The second, also replaces median filtering by the optimum Maximum Likelihood signal estimate assuming Rayleigh-distributed multiplicative B-mode ultrasound noise. The two above novel algorithms are compared to known ones (such as the SAM algorithm [3]) and to each other as to their computational efficiency and relative effectiveness in texture preservation and speckle removal.

2 Signal Adaptive Median filter based on Fractal Dimension

The Signal-Adaptive Median (SAM) filter [3] is a variable window size nonlinear filter whose output is given by:

$$\hat{x}(k,m) = y_M(k,m) + b(k,m)[y(k,m) - y_M(k,m)] \tag{2}$$

where $\hat{x}(k,m)$ is the signal estimate, $y(k,m)$ is the noisy observation at pixel (k,m), $y_M(k,m)$ is the median of the observations in an $N \times M$ window W centered on pixel (k,m) and $b(k,m)$ is a coefficient which must satisfy the following requirements:

1. it must approach 0 offering maximum noise reduction in uniform regions
2. it must approach 1 preserving and possibly enhancing the boundaries between regions of different texture in textured regions

It can be easily recognized that $b(k,m) = 0$ implies $\hat{x}(k,m) = y_M(k,m)$, while $b(k,m) = 1$ implies $\hat{x}(k,m) = y(k,m)$. An appropriate expression for such a coefficient is given by the following equation:

$$b(k,m) = \frac{1}{1+\tilde{\sigma}_q^2}\ [1 - \frac{\bar{y}^2(k,m)\tilde{\sigma}_q^2}{\sigma_y^2(k,m)}] \tag{3}$$

where $\bar{y}(k,m)$ is an estimate of E$[y(k,m)]$ over the running window W, $\tilde{\sigma}_q^2$ is the normalized variance of the multiplicative noise and σ_y^2 is the sample variance of $y(k,m)$ over the window W. The value of the factor $b(k,m)$ is used to adjust the window size W pointwize, i.e., to control how many pixels in the neighborhood of $y(k,m)$ will be median filtered, based on the local SNR, where:

$$SNR = 1 - \frac{\bar{y}^2(k,m)\tilde{\sigma}_q^2}{\sigma_y^2(k,m)} \tag{4}$$

This is done in order to avoid abrupt changes in noise suppression and to achieve a better adaptation. In flat regions, it becomes small. Near edges it approaches one. Therefore $b(k,m)$ may be considered as an edge detector, appropriate to the noise model (1) .

It is known that the Fractal Dimension (FD) may be used for the representation and classification of texture, and for edge detection and enhancement [4,8] . In the novel method proposed here, we replace SNR in (2) by an estimate of the FD. A space domain estimation of the FD is being used which is based on the fractional Brownian motion model [5,6] . According to this model a fractional Brownian motion surface must satisfy the following relationship:

$$\mathrm{E}[|y(k_2,m_2) - y(k_1,m_1)|] \propto (\sqrt{(k_2-k_1)^2 + (m_2-m_1)^2})^H \tag{5}$$

where H is the Hausdorf dimension. The FD D_s of the surface is defined by:

$$D_s = 3 - H \tag{6}$$

and, in this paper, is being calculated by the algorithm proposed in [4].

3 Signal Adaptive L_2 mean filter

In this section the following simplification of the model (1) is used:

$$y = xn \tag{7}$$

where n is assumed to be Rayleigh-distributed noise independent of x, with probability density:

$$f_n(\mathcal{N}) = \frac{\pi\mathcal{N}}{2}\exp[-\frac{\pi\mathcal{N}^2}{4}] \quad \mathcal{N} > 0 \tag{8}$$

Let us assume that we have N observations. Then the joint conditional probability density function of the observations is given by:

$$f_{\mathbf{y}|x}(\mathbf{Y}|X) = \frac{\pi^N}{2^N X^{2N}} \prod_{i=1}^{N} Y_i \exp[-\frac{\pi Y_i^2}{4X^2}] \tag{9}$$

The maximum-likelihood(ML) estimate $\hat{x}_{ML}$ is the value of x maximizing (9). Easily:

$$\hat{x}_{ML} = \frac{\sqrt{\pi}}{2}\sqrt{\frac{1}{N}\sum_{i=1}^{N} Y_i^2} \tag{10}$$

It is seen that the ML estimate (10) is simply the output of an L_2 mean filter defined in [7] multiplied by the constant $\sqrt{\pi}/2$. Therefore instead of the median estimate used in (2) , the ML estimate (10) can be used.

4 Results and Conclusions

Figure 1 illustrates the original ultrasonic image of liver that is used. Figures 2 and 3 illustrate the results of applying a Signal Adaptive ML filter using SNR and FD respectively to calculate the $b(k,m)$ factor that effects the adaptation. It can be easily seen that the FD method does a better speckle reduction than the SNR method. The Fractal Dimension of each pixel has been calculated based on a 7×7 or 5×5 window centered on that pixel.

From the computational point of view, the FD calculation is very time consuming. It takes a full 12 hours to filter a 512x512 image using 5x5 running window on an 68020 based workstation. A parallel version of the program has also been implemented on a 16 Transputer parallel computer, reducing the processing time to under 1 hour. For comparison purposes it is noted that the SNR version of SAM only requires about 35 minutes on the above-mentioned workstation.

The overall effect of such an adaptive filtering is the reduction of speckle in such a way that information inherent in the image is not affected. The better performance of the FD as a local signal activity estimator may be attributed to its texture representation and edge detection properties [8].

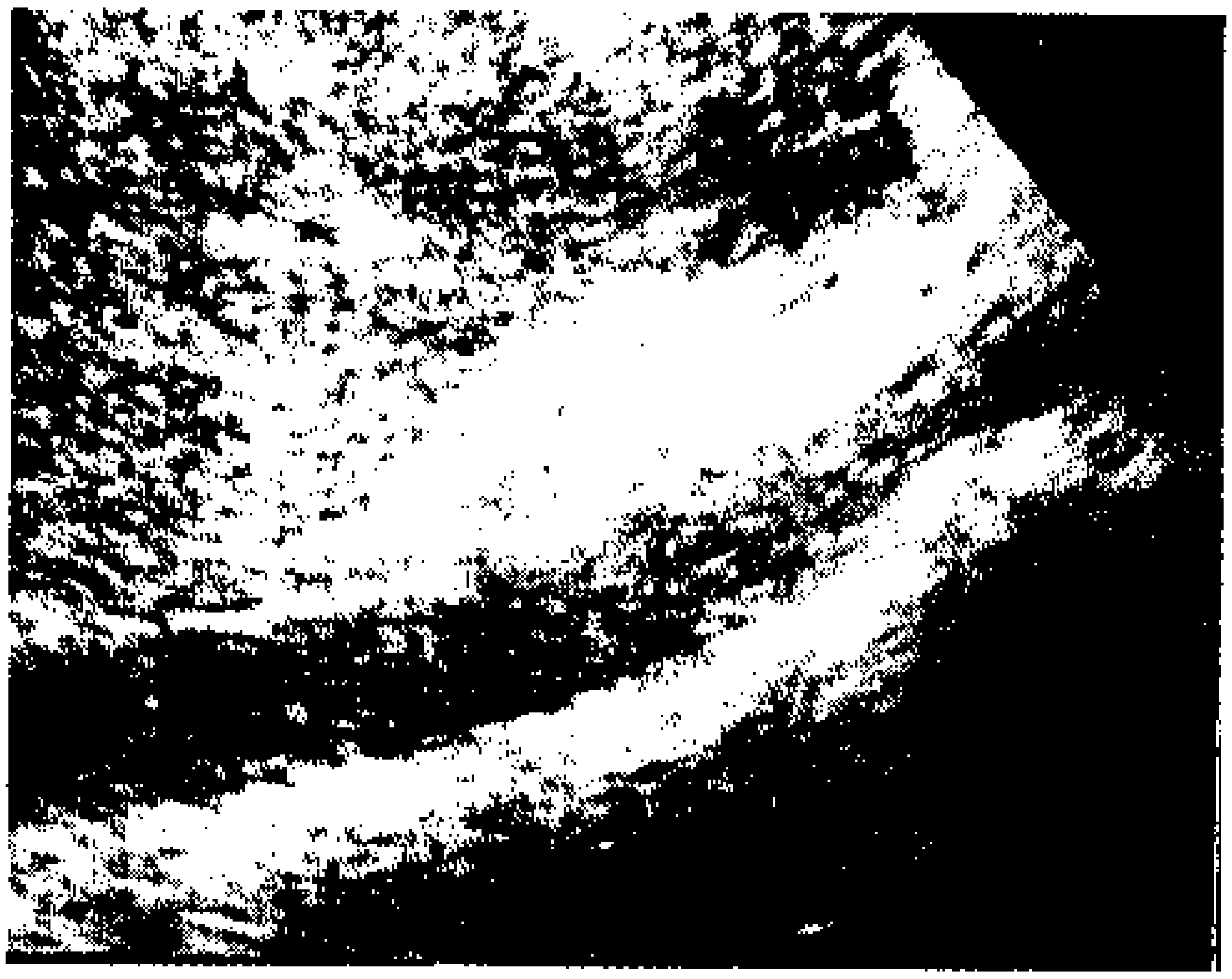
Figure 1: Original ultrasound B-mode liver scan image


Figure 2: Signal Adaptive ML filter using SNR


Figure 3: Signal Adaptive ML filter using FD

References

[1] T. Loupas, W.N. McDicken and P.L. Allan, "An adaptive weighted median filter for speckle suppresion in medical ultrasonic images", *Trans. on Circuits ans Systems*, vol. CAS-36, no. 1, January 1989 pp. – .

[2] H.E. Knutsson, R. Wilson and G.H. Granlund, "Anisotropic Nonstationary Image Estimation and its Applications: Part I-Restoration of Noisy Images", *IEEE Transactions on Communications*, Vol. COM-31, No.3, March 1983, pp. 386–406.

[3] R. Bernstein: "Adaptive Nonlinear Filters for Simultaneous Removal of Different Kinds of Noise in Images", *IEEE Trans. Circuits and Systems*, Vol. CAS-34, No.11, Nov. 1987, pp. 1275–1291.

[4] Chi-Chang Chen, J.S. Daponte and M.D. Fox, "Fractal Feature Analysis and Classification in Medical Imaging", *IEEE Trans. Medical Imaging*, Vol. 8, No. 2, June 1989, pp. 133–142.

[5] Heinz-Otto Peitgen, Dietmar Saupe, Editors, *The Science of Fractal Images*, Springer-Verlag, 1988.

[6] Michael Barnsley: *Fractals Everywhere*, Academic Press, Inc., 1988.

[7] I. Pitas, A.N. Venetsanopoulos, "Edge detectors based on nonlinear filters",*IEEE Trans. on Pattern Anal. and Machine Intelligence*, vol. PAMI-8, no. pp. 538-550, July 1986.

[8] T. Lundahl, W.J. Ohley, S.M. Kay and R. Siffert: "Fractional Brownian Motion: A Maximum Likelihood Estimator and its Application to Image Texture", *IEEE Trans. Medical Imaging*, Vol. 5, No. 3, Sept. 1986, pp. 152-161.