A New Medical Feature Enhancing Speckle Suppression Method for Ultrasound Images of the Neonatal Brain

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Abstract—**In this paper we introduce a new smoothing technique based on a noise model for the speckle noise as represented in the image. Using this model and measurements reported earlier in literature we are able to distinguish speckle noise from important resolvable details. All individual speckles are located, and exploiting our knowledge on the speckle classification, the filter removes the noise speckles, while it preserves valuable details.**

We show that applying the proposed technique yields a significant speckle suppression in the image, while valuable image data are preserved.

Keywords—**speckle; medical ultrasound; filtering; neonatal brain**

I. Introduction

Ultrasound imaging is gaining more and more importance in medical practice nowadays. It is especially useful in imaging soft tissue like liver, spleen, lungs, the heart, and the neonatal brain. Advantages of ultrasound imaging are that it is quick, cheap, and the machinery is highly portable. An ultrasound image can be made in a few seconds, while standing next to the bed of the patient. This is especially useful when the patient is in need of intensive care, as is usually the case with neonates which are born too early.

A common problem with the interpretation of ultrasound images though, is the presence of speckle noise. Several techniques for suppressing speckle noise have been developed [1–6]. Most of them involve the use of general speckle statistics, and not all are equally well-suited for medical ultrasound images, because they do not take into account the special features that are typical for medical images. Examples of such features are: bright large scale interfaces between organs, structure with dimensions comparable to speckle size, and boundaries between two regions with slightly different grey levels.

The new speckle suppression method we present in this article, is designed to remove a lot of speckle noise, while preserving valuable medical image data. It is based on the following noise model, which is adopted for speckle noise in images:

$$x = s + n\sqrt{s}.$$

Herein represent: x the observed signal, s the noise-free signal, and n the noise [5]. This model implies that, on homogeneous regions, where s can be assumed constant, the image variance is proportional to the mean.

This model is particularly suitable for our purpose, since the presented filter works on the images as displayed by the ultrasound machine, rather than the envelope detected echo signal. Wagner et al. have shown that the envelope detected echo signal of the fully developed speckle has the Rayleigh distribution with the mean proportional to the standard deviation [7,8]. However, in [5] the above mentioned model is proven to hold for the images of speckle, i.e., after nonlinear processing such as logarithmic compression, which is performed in the display system of the ultrasound machine.

In [6] this has been confirmed experimentally. Around each pixel (i, j) an 11×11 window W was taken, and the mean and variance were calculated as follow:

$$\mu_{(i,j)} = \frac{1}{W^2} \sum_{m,n=-W/2}^{W/2} x_{(i-m,j-n)}$$

$$\sigma^2_{(i,j)} = \frac{1}{W^2} \sum_{m,n=-W/2}^{W/2} (x_{(i-m,j-n)} - \mu_{(i,j)})^2.$$

The signal-to-noise-ratio $\rho_{(i,j)}$ is defined as:

$$\rho_{(i,j)} = \frac{\sigma^2_{(i,j)}}{\mu_{(i,j)}}$$

For phantom images a value of $\rho_{(i,j)} = 2.5$ was found, and for real medical images a value of $\rho_{(i,j)} = 2.0$.

Fig. 1. Ultrasound image.

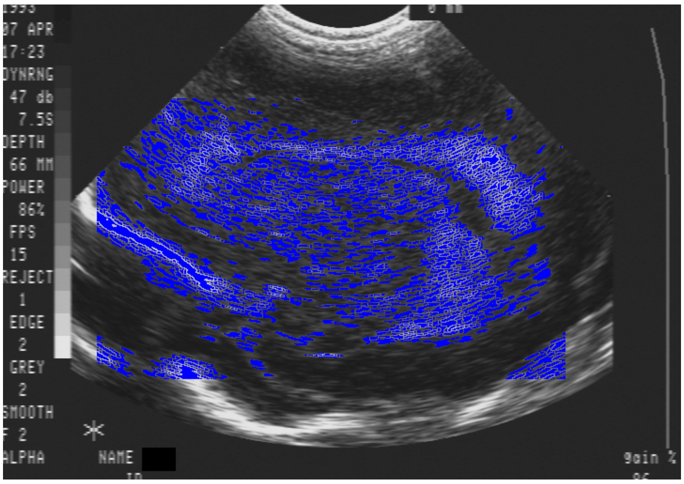

Fig. 2. Speckles as found by proposed technique.

In the next paragraph we will describe a new speckle suppression filter which exploits this information in removing the speckle noise, while preserving valuable medical image data at the same time. We will apply it on a couple of test images, and conclude that the proposed technique outperforms several well-known classical techniques.

II. Filter

In order to filter the speckle noise without losing resolvable objects in the image, we developed a technique which identifies each individual speckle, and decides, depending on the signal-to-noise-ratio of its direct environment, whether it is a resolvable object or noise. We start with giving a detailed description of the method. After that we will motivate each step:

1) Let Γ be the global maximum grey value in the image. Choose a pixel (i, j) with grey value $\alpha_{(i,j)} = \Gamma$. This pixel serves as a seed pixel for a region procedure, controlled by the grey value of the pixels. We consider the eight surrounding pixels of our seed pixels. Each of those which differs in absolute value less than a predefined threshold T from Γ is appended to the region. After that we again consider each surrounding pixel of the region grown so far, compare its grey value with Γ, and depending on that, decide to append it to the region or not. We continue doing this till none of the surrounding pixels has a grey value within the specified range anymore.

In short: to test whether a pixel (m, n), with grey value $\alpha_{(m,n)}$, belongs to the region of a seed pixel (i, j), the following must be satisfied:

- Pixel (m, n) is "connected" to pixel (i, j),
- $\alpha_{(m,n)} > \Gamma - T$,
- Pixel (m, n) does not belong to a speckle which has already been grown, or to the border of one of those speckles (i.e., (m, n) is also not adjacent to one of the earlier grown speckles).

In this way we isolate one single speckle Σ.

2) Next we determine the centre of gravity g_Σ of Σ, and take a square W of 11×11 pixels around g_Σ. Within W we calculate the signal-to-noise-ratio ρ_Σ as described in paragraph I

3) If $\rho_\Sigma > 2.0$, we conclude that the speckle can be considered as a resolvable object, and hence the speckle Σ need not be removed. We go back to 1) and grow the next speckle. Note that from now we do not take Σ and all pixels adjacent to it (we call this the "border" of Σ) into consideration anymore. (So Γ will now be the maximum grey value of all pixels in the image except those in Σ and its border).

4)If $\rho_\Sigma <= 2.0$ then the pixel is located in a homogeneous region, and hence is noise that should be removed. We calculate the mean ν_Σ of the grey values of all the pixels adjacent to Σ (its border), and give all pixel of Σ the value ν_Σ. In this way actually "cut off" the speckle.

5) We repeat the whole process (from step 1), in which we disregard Σ and its border. We continue doing this until the maximum Γ becomes smaller than a fixed lower border Λ.

Both T and Λ are adjustable parameters of the filter. In all images we processed, we obtained optimal results with $T = 23$ and $\Lambda = 80$.

In the figures 2 and **??** the speckles, as they are found by step 1), are indicated.

Fig. 3. Original image.

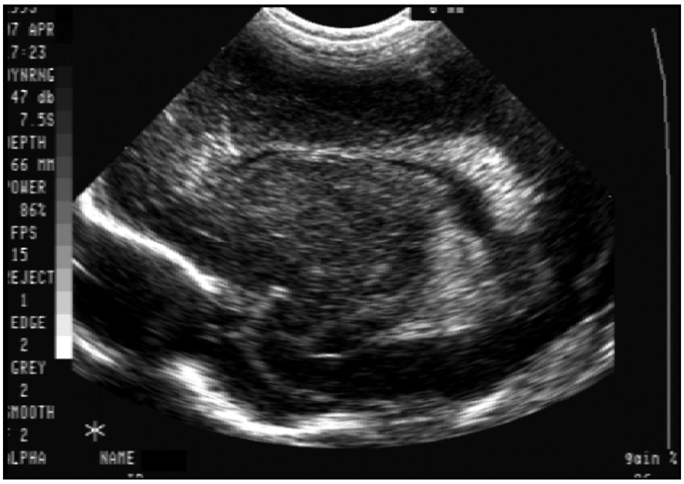

Fig. 4. Lee filter.

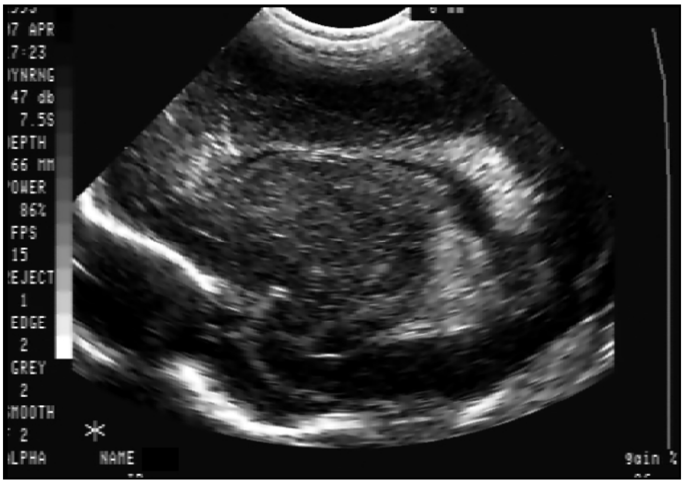

Fig. 5. Frost filter.

In step 1) we hit the core of the method by first identifying the individual speckles. According to the specific characteristics of speckle, they are located by means of their higher grey value. A region growing procedure is applied to isolate them. For each speckle found this way, the signal-to-noise-ratio of its direct neighbourhood is calculated, and, exploiting our knowledge on the signal-to-noise-ratio of homogeneous tissue, we determine whether the speckle is noise, in which case it is removed, or a resolvable object. This way we succeed in removing lot of speckle noise, while the valuable medical features are well-preserved.

III. Experimental Results

We applied the proposed method on the image in figure 3 and 7. The result is shown in figures 6 and 10. In figures 4, 8, 5, and 9 we have processed the same images with two classical speckle suppression filters, namely the Lee [1] and the Frost filter [2]. The results are shown on the next pages. Our conclusion is, that the proposed method performs much better with regard to speckle suppression than the Lee and the Frost filter, and in addition leaves the original contrast better intact. Furthermore our method is computationally not intensive in comparison with i.e. wavelet based techniques. Processing an image of 722 $\times$ 506 pixels (this is the size of the example image) on a Pentium II took 25 seconds.

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Fig. 6. Proposed method.

Fig. 7. Original image.

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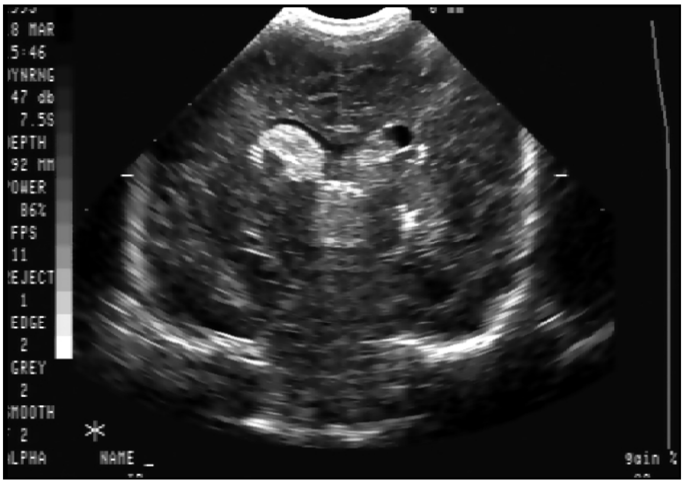

Fig. 8. Lee filter.

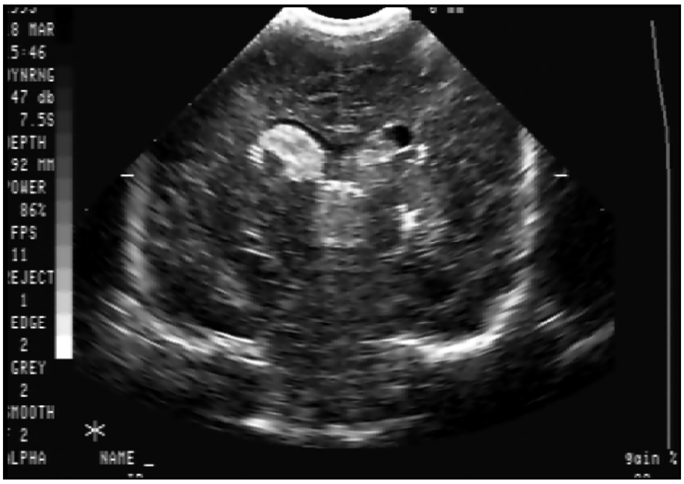

Fig. 9. Frost filter.

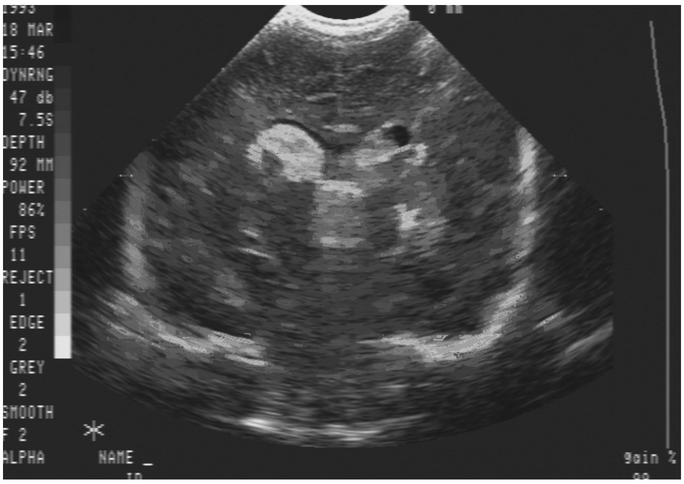

Fig. 10. Proposed method.